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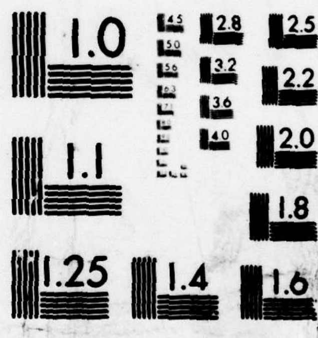
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TWO-DIMENSIONAL DESCRIPTION OF THE NATURAL ATMOSPHERE INCLUDING ACTIVE WATER VAPOR MODELING AND POTENTIAL PERTURBATIONS DUE TO NO_x AND HO_x AIRCRAFT EMISSIONS

George F. Widhopf
and
Leslie Glatt

April 15, 1979

FINAL REPORT

Prepared for

HIGH ALTITUDE POLLUTION PROGRAM

U.S. DEPARTMENT OF TRANSPORTATION

FEDERAL AVIATION ADMINISTRATION
Office of Environment and Energy
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16. Abstract

The status of the Aerospace time-dependent two-dimensional photochemical model of the atmosphere as developed under contract to the FAA High Altitude Pollution Program (HAPP) is presented, together with the significant findings obtained during this study. Model improvements are described, as are the chronological effects of recent hydroperoxyl reaction rate measurements on the state of the natural and perturbed atmosphere. Comparisons with available data are made to elucidate our current ability to calculate the distribution of many trace species in the natural atmosphere. In general, the results are in relatively good agreement with available data; however, the most serious problem is the significant overprediction of stratospheric HNO_3 concentration. When the most recent chemical reaction rates are used and ClO_x is included, estimates of the effect of combined NO_x and HO_x emissions from projected future fleets of subsonic and supersonic aircraft indicate a resulting increase in ozone level in both the stratosphere and troposphere, with the significant change occurring in the troposphere. Peak increases in total ozone column are currently estimated to be 3.5 percent during summer-fall. The increase from previous estimates of 1.5 percent is primarily a result of the recently measured higher hydroxyl reaction rates. The effect of HO_x is actively modeled and, based on a currently projected 1990 fleet (a large number of subsonic and a small number of supersonic aircraft), the effect of HO_x emissions on the total ozone column has been found small in comparison to the corresponding effect of NO_x emissions.

17. Key Words

ozone
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stratosphere
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FIGURES (Continued)

FIGURES (Continued)

1. INTRODUCTION

The potential effect of various pollutants on the state of the earth's ozone shield has been extensively investigated in the last decade. These studies have concentrated primarily on the effect of NO_x and ClO_x pollutants which result from various anthropogenic sources. Another potential pollutant which has not been adequately investigated is water vapor.

Water vapor is the main source of hydroperoxyls in the atmosphere and is also a major component of aircraft exhaust emissions. Thus, a comprehensive evaluation of the effect of aircraft emissions on ozone must consider the effect of this species. Previous calculations of the effect of NO_x aircraft emissions on ozone have shown that tropospheric effects are very important in modeling the effect of NO_x on ozone [Widhopf, et al. (1977); Hidalgo and Crutzen (1977)]. Since rainout is one of the controlling mechanisms in determining the distribution of water vapor, and rainout/washout effects are important in determining the rate at which NO_x is removed from the troposphere, a model is needed which adequately predicts the distribution of water vapor including the effect of rainout. This type of model was developed for use in our two-dimensional time-dependent model of the atmosphere in order to study both the natural and perturbed atmosphere.

During the course of this study, various important hydroperoxyl reaction rates were measured for the first time. These rates increased the relative importance of HO_x with regard to NO_x on the chemical structure of the atmosphere and have resulted in dramatic changes in the atmospheric distribution of some trace species. As a result of the sequential manner in which these measurements were made, a number of interim results were obtained.

Results for the state of the natural atmosphere are discussed in this report, including the latest two-dimensional model results which consider the effect of ClO_x. In addition, further estimates have been made of the

potential effect of NO_x and HO_x emissions from projected future fleets of subsonic and supersonic aircraft. Comparisons are also made with available data in order to elucidate areas where additional measurements of reaction rates and species distributions are needed.

2. MODEL

The model is a time-dependent phenomenological photochemical model of the atmosphere in which the hydrodynamic variables (mean atmospheric density, temperature, turbulent diffusion coefficients, and mean meridional winds) either are specified, or are obtained indirectly, from observations as a function of time during the year and used to solve the system of species conservation equations for the meridional distribution of trace species throughout the year. The formulation of the model, discussed in Widhopf and Taylor [1974] and Widhopf [1975], basically is designed to examine relatively small changes in the ozone concentration as a function of the time of year throughout the meridional plane, since any resultant changes in the species concentration occurring as a result of the introduction of a pollutant are not coupled back to the atmospheric dynamics or temperature distributions.

The governing species conservation equation is derived following the general procedure outlined by Reed and German [1965] for representing the turbulent transport flux due to large-scale eddies. In the meridional plane, this equation, written in terms of the mass mixing ratio, is of the form

$$\frac{\partial \rho Y_i}{\partial t} + \frac{\partial \rho w Y_i}{\partial z} + \frac{1}{\cos\phi}\frac{\partial \rho v Y_i \cos\phi}{r\partial\phi} = \frac{\partial}{r\partial\phi}\left\{\rho k_{\phi z}\frac{\partial Y_i}{\partial z} + \rho k_{\phi\phi}\frac{\partial Y_i}{r\partial\phi}\right\}$$
$$+ \frac{\rho}{r}\left\{(2k_{zz} - k_{\phi z}\tan\phi)\frac{\partial Y_i}{\partial z} + (2k_{z\phi} - k_{\phi\phi}\tan\phi)\frac{\partial Y_i}{r\partial\phi}\right\}$$
$$+ \frac{\partial}{\partial z}\left\{\rho k_{zz}\frac{\partial Y_i}{\partial z} + k_{\phi z}\frac{\partial Y_i}{r\partial\phi}\right\} + \omega_i + S_i, \quad i=1,2\ldots \tag{1}$$

where Y_i is the mass mixing ratio ρ_i/ρ of the i^{th} chemical species; ρ is the local mean atmospheric density; t is the temporal variable; $r = z + R_e$, where R_e is the mean radius of the earth and z is the altitude measured from and

normal to the earth's surface; ϕ is the latitude; ω_i is the photochemical rate of production/depletion of the i^{th} species; and S_i is the local source/sink effect. The components of the tensor $k_{\alpha\beta}$ represent the diffusion coefficient in the respective directions arising from large-scale eddy motions, whereas v and w are the components of the mean circulation in the meridional and vertical directions, respectively. This equation is solved for each of the trace species considered.

3. CHEMICAL MODEL

The chemical system considered in this investigation includes the following species: $O(^1D)$, $O(^3P)$, O_2, O_3, N, NO, NO_2, NO_3, N_2, N_2O, N_2O_5, H, OH, HO_2, H_2O, H_2O_2, HNO_3, CO, and CH_4. Also included are the important ClO_x species Cl, ClO, $ClONO_2$, and HCl which are produced in the atmosphere as a result of the release at the earth's surface of CF_2Cl_2, $CFCl_3$, CCl_4, and CH_3Cl, among others. Smog type reactions initiated by the oxidation of methane by OH, which have been shown to be potentially important in the lower regions of the atmosphere, particularly for the evaluation of aircraft emissions effects through the work of Hidalgo and Crutzen [1977] and Widhopf, et al. [1977] are also included. These reactions involve the species CH_3, CHO, CH_2O, CH_3O, CH_3O_2, and CH_3O_2H. The specific reaction systems and the associated reaction rate coefficients used in this investigation are tabulated in Tables I through III. Table I lists the reactions and associated rates used in Widhopf, et al. [1977], while Tables II-a, II-b, and III list changes introduced in subsequent studies which are discussed in this report. Specifically, Table II-a lists additional reactions and updated reaction rates that were recommended by the NASA-CFM study [1977] together with the new measurements of the rate for the reaction $NO + HO_2 \rightarrow NO_2 + OH$. Table II-b includes the new rate measurement for the reaction $HO_2 + O_3 \rightarrow OH + 2O_2$. Table III includes the ClO_x system together with the most recent temperature-dependent rate for the reaction $NO + HO_2 \rightarrow NO_2 + OH$, and a pressure-dependent rate for the reaction $CO + OH \rightarrow CO_2 + H$.

Computation of the absorption of solar radiation is an integral step in determining the chemical structure of the atmosphere, since many of the important reactions in the atmosphere are photochemical processes. The diurnally averaged local photolysis rates J_i are calculated at every location in the atmosphere at every third time step by a technique developed by Kramer and Widhopf [1978], using the solar flux data compiled by Ackerman [1971]. The

time variation of the solar zenith angle with latitude and solar declination is included in the determination of the photolysis rates J_i. The absorption cross sections utilized to compute J_i for the various species are outlined in Widhopf [1975] and the NASA-CFM study [1977].

In order to properly model the chemistry of the species N_2O_5, NO_3, and $ClONO_2$ which have important nighttime chemistry, a diurnal averaging was introduced similar to that of Turco and Whitten [1978]. Here, the diurnal variation of the concentration is modeled as a constant daytime level followed by a constant nighttime level. The ratio between these two states can be calculated and is used to average the chemical production/depletion terms to account for daytime-nighttime chemistry. This change allows for an appropriate modeling of the nighttime chemistry for NO_3, N_2O_5, and $ClONO_2$ while improving the calculated relative concentrations of NO_2 to NO.

The effect of multiple scattering was also found to have a significant effect on distributions of NO and NO_2 as well as other species. Therefore, it was included in the model using the work of Luther, et al. [1978].

TABLE I. CHEMICAL REACTIONS AND RATE COEFFICIENTS

	REACTION	RATE COEFFICIENT[a]
1.	$O(^3P) + O_3 \rightarrow 2O_2$	$1.9(10)^{-11} \exp[-2300/T]$
2.	$O_2 + h\nu \rightarrow 2O(^3P)$	J_2
3.	$O_3 + h\nu \rightarrow O(^3P) + O_2$	J_3
4.	$NO_2 + h\nu \rightarrow O(^3P) + NO$	J_4
5.	$O(^3P) + O_2 + M \rightarrow O_3 + M$	$1.07(10)^{-34} \exp[510/T]$
6.	$O(^3P) + NO_2 \rightarrow O_2 + NO$	$9.1(10)^{-12}$
7.	$O_3 + NO \rightarrow O_2 + NO_2$	$9(10)^{-13} \exp[-1200/T]$
8.	$O_3 + NO_2 \rightarrow O_2 + NO_3$	$1.23(10)^{-13} \exp[-2470/T]$
	$\lvert NO_3 + h\nu \rightarrow 2/3[NO_2 + O(^3P)] + 1/3[NO + O_2]\rvert$	
9.	$O_3 + OH \rightarrow O_2 + HO_2$	$1.6(10)^{-12} \exp[-1000/T]$
10.	$NO + HO_2 \rightarrow OH + NO_2$	$2.3(10)^{-13}$
11.	$O(^3P) + H_2O \rightarrow OH + OH$	0.0
12.	$OH + NO_2 + M \rightarrow HNO_3 + M$	$\dfrac{2.76(10)^{-13} \exp[880/T]}{1.166(10)^{18} \exp[220/T] + [M]}$
13.	$HNO_3 + h\nu \rightarrow OH + NO_2$	J_{13}
14.	$HO_2 + O_3 \rightarrow OH + O_2 + O_2$	$1(10)^{-13} \exp[-1250/T]$
15.	$HO_2 + O(^3P) \rightarrow OH + O_2$	$3(10)^{-11}$
16.	$OH + HO_2 \rightarrow H_2O + O_2$	$2(10)^{-11}$
17.	$OH + HNO_3 \rightarrow H_2O + NO_3$	$8.9(10)^{-14}$
	$\lvert NO_3 + h\nu \rightarrow 2/3[NO_2 + O(^3P)] + 1/3[NO + O_2]\rvert$	
18.	$H_2O_2 + h\nu \rightarrow OH + OH$	J_{18}
19.	$H_2O_2 + OH \rightarrow H_2O + HO_2$	$1.7(10)^{-11} \exp[-910/T]$
20.	$HO_2 + HO_2 \rightarrow H_2O_2 + O_2$	$1.7(10)^{-11} \exp[-500/T]$
21.	$O_3 + h\nu \rightarrow O_2 + O(^1D)$	J_{21}
22.	$O(^1D) + M \rightarrow M + O(^3P)$	$2.2(10)^{-11} \exp[92/T]$
23.	$N_2O + h\nu \rightarrow N_2 + O(^1D)$	J_{23}
24.	$N_2O + O(^1D) \rightarrow N_2 + O_2$	$5.7(10)^{-11}$
25.	$N_2O + O(^1D) \rightarrow NO + NO$	$5.7(10)^{-11}$

	REACTION	RATE COEFFICIENT[a]
26.	$NO + h\nu \rightarrow N + O(^3P)$	J_{26}
27.	$N + O_2 \rightarrow NO + O(^3P)$	$1.02(10)^{-14} T \exp[-3130/T]$
28.	$N + NO \rightarrow N_2 + O(^3P)$	$2.7(10)^{-11}$
29.	$N + NO_2 \rightarrow NO + NO$	0.0
30.	$N_2 + O(^1D) + M \rightarrow N_2O + M$	$2.8(10)^{-36}$
31.	$NO_2 + N \rightarrow N_2O + O(^3P)$	$1.4(10)^{-12}$
32.	$O(^1D) + H_2O \rightarrow OH + OH$	$2.32(10)^{-10}$
33.	$O(^1D) + CH_4 \rightarrow OH + CH_3$	$1.38(10)^{-10}$
34.	$OH + O(^3P) \rightarrow O_2 + H$	$4.2(10)^{-11}$
35.	$H + O_2 + M \rightarrow HO_2 + M$	$2.08(10)^{-32} \exp[290/T]$
36.	$H + O_3 \rightarrow OH + O_2$	$1.23(10)^{-10} \exp[-562/T]$
37.	$NO + O(^3P) + M \rightarrow NO_2 + M$	$3.96(10)^{-33} \exp[940/T]$
38.	$OH + OH \rightarrow H_2O + O(^3P)$	$1(10)^{-11} \exp[-550/T]$
39.	$N + O_3 \rightarrow NO + O_2$	$5.7(10)^{-13}$
40.	$HO_2 + h\nu \rightarrow OH + O(^3P)$	J_{40}
41.	$OH + CH_4 \rightarrow H_2O + CH_3$	$2.36(10)^{-12} \exp[-1710/T]$
42.	$2OH + M \rightarrow H_2O_2 + M$	$2.5(10)^{-33} \exp[2500/T]$
43.	$H_2O_2 + O(^3P) \rightarrow OH + HO_2$	$2.75(10)^{-12} \exp[-2125/T]$
44.	$CO + OH \rightarrow H + CO_2$	$\log_{10}K$ -12.95 + $3.94(10)^{-4} T$
45.	$CH_2O + h\nu \rightarrow H_2 + CO$	J_{45}
46.	$CHO + O_2 \rightarrow HO_2 + CO$	$5(10)^{-12}$
47.	$CH_3 + O_2 + M \rightarrow CH_3O_2 + M$	$2.6(10)^{-31}$
48.	$CH_3O_2 + NO \rightarrow CH_3O + NO_2$	$1.5(10)^{-12} \exp[-500/T]$
49.	$CH_3O_2 + HO_2 \rightarrow CH_3O_2H + O_2$	$3.0(10)^{-11} \exp[-500/T]$
50.	$CH_3O_2H + h\nu \rightarrow CH_3O + OH$	J_{50}
51.	$CH_3O + O_2 \rightarrow CH_2O + HO_2$	$1.6(10)^{-13} \exp[-3300/T]$
52.	$CH_2O + h\nu \rightarrow H + CHO$	J_{52}
53.	$CH_2O + OH \rightarrow H_2O + CHO$	$1.4(10)^{-11}$

[a] Units in sec^{-1}, $cm^3 sec^{-1}$ and $cm^6 sec^{-1}$ for unimolecular, bimolecular and trimolecular reactions.

TABLE IIa. ADDITIONAL REACTIONS AND NEW NASA (1977) RATES

	REACTION	RATE COEFFICIENT[a]		REACTION	RATE COEFFICIENT[a]
7.	$O_3 + NO \rightarrow O_2 + NO_2$	$2.1\ 10^{-12}\ \exp[-1450/T]$	53.	$CH_2O + OH \rightarrow H_2O + CHO$	$3\ 10^{-11}\ \exp[250/T]$
8	$O_3 + NO_2 \rightarrow O_2 + NO_3$	$1.2\ 10^{-13}\ \exp[-2450/T]$	54.	$NO_3 + NO_2 + M \rightarrow N_2O_5 + M$	$1.9\ 10^{-30}(3+5C)/[(1+5C)(3+C)]$
9.	$O_3 + OH \rightarrow O_2 + HO_2$	$1.5\ 10^{-12}\ \exp[-1000/T]$			$C = 5\ 10^{-19}[M]$
10.	$NO + HO_2 \rightarrow OH + NO_2$	$8\ 10^{-12}$	55.	$N_2O_5 + M \rightarrow NO_3 + NO_2 + M$	$D(4+F)/[(1+F)(4+F)]$
12.	$OH + NO_2 + M \rightarrow HNO_3 + M$	$\log_{10}(k) = -AT/(B+T) - 0.5\ \log_{10}(T/280)$			$D = 2.2\ 10^{-5}\ \exp[-9700/T]$
14.	$HO_2 + O_3 \rightarrow OH + O_2 + O_2$	$7.3\ 10^{-14}\ \exp[-1275/T]$			$E = 5.7\ 10^{14}\ \exp[-10600/T]$
15.	$HO_2 + O \rightarrow OH + O_2$	$3.5\ 10^{-11}$			$F = B[M]/E$
16.	$OH + HO_2 \rightarrow H_2O + O_2$	$3\ 10^{-11}$	56.	$NO_3 + h\nu \rightarrow 2/3(NO_2 + O) + 1/3(NO + O_2)$	
17.	$OH + HNO_3 \rightarrow H_2O + NO_3$	$8\ 10^{-14}$	57.	$N_2O_5 + h\nu \rightarrow NO_2 + NO_3$	
19.	$H_2O_2 + OH \rightarrow H_2O + HO_2$	$1\ 10^{-11}\ \exp[-750/T]$	58.	$NO_3 + NO \rightarrow 2NO_2$	$8.7\ 10^{-12}$
20.	$HO_2 + HO_2 \rightarrow H_2O_2 + O_2$	$2.5\ (10)^{-12}$	59.	$NO_2 + O + M \rightarrow NO_3 + M$	$1\ 10^{-31}$
24.	$N_2O + O(^1D) \rightarrow N_2 + O_2$	$5.5\ 10^{-11}$	60.	$CO_2 + h\nu \rightarrow O + CO$	
25.	$N_2O + O(^1D) \rightarrow NO + NO$	$5.5\ 10^{-11}$	61.	$H_2 + O(^1D) \rightarrow OH + H$	$9.9\ 10^{-11}$
27.	$N + O_2 \rightarrow NO + O$	$5.5\ (10)^{-12}\ \exp[-3220/T]$	62.	$O(^1D) + CH_4 \rightarrow H_2 + CH_2O$	$1.4\ 10^{-11}$
28.	$N + NO \rightarrow N_2 + O$	$8.2\ 10^{-11}\ \exp[-410/T]$	63.	$O + CH_4 \rightarrow CH_3 + OH$	$3.5\ 10^{-11}\ \exp[-4450/T]$
30.	$N_2 + O(^1D) + M \rightarrow N_2O + M$	$3.5\ 10^{-37}$	64.	$CH_2O + O \rightarrow OH + CHO$	$2\ 10^{-11}\ \exp[-1450/T]$
31.	$NO_2 + N \rightarrow N_2O + O$	$2\ 10^{-11}\ \exp[-800/T]$			
34.	$OH + O \rightarrow O_2 + H$	$4.2\ 10^{-11}$			
37.	$NO + O + M \rightarrow NO_2 + M$	$1.55\ 10^{-32}\ \exp[584/T]$			
39.	$N + O_3 \rightarrow NO + O_2$	$5\ 10^{-12}\ \exp[-650/T]$		$A = A_1 + A_2z + A_3z^2 + A_4z^3$	
42.	$2OH + M \rightarrow H_2O_2 + M$	$1.25\ 10^{-32}\ \exp[900/T]$		$B = B_1 + B_2z + B_3z^2$	
44.	$CO + OH \rightarrow H + CO_2$	$1.4\ 10^{-13}$		$A_1 = 31.62273$	$B_1 = -327.372$
46.	$CHO + O_2 \rightarrow HO_2 + CO$	$6\ 10^{-12}$		$A_2 = -0.258304$	$B_2 = 44.558 + z\ \log_{10}[0.94[N_2]]$
48.	$CH_3O_2 + NO \rightarrow CH_3O + NO_2$	$1.5\ 10^{-12}$		$A_3 = -0.0889287$	$B_3 = -1.38092$
49.	$CH_3O_2 + HO_2 \rightarrow CH_3O_2H + O_2$	$2.5\ 10^{-12}$		$A_4 = 2.520173(10)^{-3}$	

[a]Units in sec^{-1}, $cm^3 sec^{-1}$ and $cm^6 sec^{-1}$ for unimolecular, bimolecular and trimolecular reactions.

TABLE IIb. CHEMICAL REACTIONS AND RATE COEFFICIENTS

REACTION	RATE COEFFICIENT
14. $HO_2 + O_3 \rightarrow OH + 2O_2$	$1.4(10)^{-14}\ \exp[-580/T]$

TABLE III. CHLORINE CHEMICAL REACTION AND RATE COEFFICIENTS

REACTION	RATE COEFFICIENT
10. $NO + HO_2 \rightarrow OH + NO_2$	$3.3(10)^{-12}\ \exp[254/T]$
44. $CO + OH \rightarrow H + CO_2$	$1.4(10)^{-13} + 7.33(10)^{-33}[M]$
65. $Cl + O_3 \rightarrow ClO + O_2$	$2.7(10)^{-11}\ \exp[-257/T]$
66. $ClO + O(^3P) \rightarrow Cl + O_2$	$7.7(10)^{-11}\ \exp[-130/T]$
67. $ClO + NO \rightarrow Cl + NO_2$	$1(10)^{-11}\ \exp[200/T]$
68. $CH_4 + Cl \rightarrow HCl + CH_3$	$7.3(10)^{-12}\ \exp[-1260/T]$
69. $Cl + H_2 \rightarrow HCl + H$	$3.5(10)^{-11}\ \exp[-2290/T]$
70. $HO_2 + Cl \rightarrow HCl + O_2$	$3(10)^{-11}$
71. $OH + HCl \rightarrow H_2O + Cl$	$3(10)^{-12}\ \exp[-425/T]$
72. $HCl + O(^3P) \rightarrow Cl + OH$	$1.1(10)^{-11}\ \exp[-3370/T]$
73. $Cl + OH \rightarrow HCl + O(^3P)$	$1(10)^{-11}\ \exp[-2970/T]$
74. $ClO + h\nu \rightarrow Cl + O(^3P)$	J_{74}
75. $HCl + h\nu \rightarrow H + Cl$	J_{75}
76. $ClO + NO_2 + N_2 \rightarrow ClONO_2 + N_2$	$\dfrac{3.3(10)^{-23}\ T^{-3.34}}{1 + 8.7(10)^{-9}[M]^{1/2}\ T^{-0.6}}$
77. $ClONO_2 + h\nu \rightarrow ClO + NO_2$	J_{77}
78. $ClONO_2 + O(^3P) \rightarrow ClO + NO_3$	$3(10)^{-12}\ \exp[-808/T]$
79. $ClO + ClO \rightarrow ClO + Cl + O(^3P)$	$2.1(10)^{-12}\ \exp[-2200/T]$
80. $ClO + ClO \rightarrow 2Cl + O_2$	$1.5(10)^{-12}\ \exp[-1238/T]$

4. BOUNDARY CONDITIONS

The computational domain considered in this investigation extends from the north to the south pole, with a 10° meridional resolution, and from the surface to 50 km, with a vertical resolution of $\Delta z = 2$ km from the surface to 12 km, $\Delta z = 1$ km up to 35 km, and $\Delta z = 2.5$ km up to the upper boundary. At the polar regions, a zero latitudinal flux is assumed.

A fixed ozone concentration $[6(10)^{11}$ mol/cm$^3]$ was imposed at the lower boundary, as interpreted from the meridional distributions compiled by Dütsch [1971] and Hering and Borden [1964-67] [as summarized in the data compilation of Wu (1973)]. The concentration of N_2O at the lower boundary was prescribed as an average value (0.31 ppmv) interpreted from the tropospheric measurements of Schütz, et al. [1970] and Goldman, et al. [1973]. The latitudinal variation of the mass mixing ratio of CO at the surface was interpreted from the measurements of Seiler [1974]. The mass mixing ratio of CH_4 (1.34 ppmv) at the lower boundary was specified from the measurements of Ehhalt, et al. [1973, 1974]. Injection of NO and NO_2 resulting from the anthrophotogenic activities was specified at the lower boundary as interpreted from the estimates of Robinson and Robbins [1971]. The species $O(^3P)$, $O(^1D)$, OH, N, and H were taken to be in photochemical equilibrium at the lower boundary because of their relatively short lifetimes, whereas H_2O, HNO_3, NO_2, NO, HO_2, H_2O_2, N_2O_5, NO_3, and ClO_x were removed from the troposphere by simulating atmospheric rainout/washout. The species H_2O, HNO_3, H_2O_2, HO_2, N_2O_5, NO_3, and ClO_x are removed at the average rates defined by Junge [1963], whereas NO_2 and NO were assumed to be removed at one-tenth this rate. The rainout/washout model is discussed in more detail in a subsequent section.

The species $O(^3P)$, $O(^1D)$, O_3, OH, HO_2, H_2O_2, N, H, Cl, ClO, and $ClONO_2$ were assumed to be in photochemical equilibrium at the upper boundary, whereas the mass mixing ratios of NO_2, N_2O, H_2O, N_2O_5, NO_3, CH_4, CO, and HNO_3 were continued analytically to the upper boundary by a

second-order extrapolation in space and time described by Widhopf [1975] and Widhopf and Taylor [1974]. This extrapolation allows the use of centered spatial differencing at this boundary while also eliminating the necessity of specifying a boundary condition for these species at this location. It is an accurate and stable method of evaluating conditions at computational boundaries [Widhopf and Victoria (1973)] when the physical mechanisms interior to the computational domain govern the boundary value. This is the case for N_2O, NO_2, CH_4, N_2O_5, NO_3, H_2O, and HNO_3, which are being transported up into the higher regions of the stratosphere.

5. TRANSPORT DATA

The meridional distributions of both mean density and temperature were specified using the data obtained from 10 years of observations which were analyzed and compiled by Louis [1973, 1974]. These averaged data are specified from the surface to 68 km for the entire meridional plane and for each of the four seasons. A tabulation of the temperature is included in the Appendix.

Luther [1973a, b] has analyzed the heat transfer, temperature, and wind variance data of Oort and Rasmussen [1971] using the procedure outlined by Reed and German [1965] for defining the components of the anisotropic turbulent eddy diffusivity tensor. The three components $k_{\phi\phi}$, $k_{\phi z}$, and k_{zz} are specified for the northern hemisphere from the surface to 60 km. Values for the components of the diffusivity tensor in regions where observational data were not available were obtained by Luther by extrapolation, using the results of Wofsy and McElroy [1973] and Newell, et al. [1966]. These coefficients are specified for each month and initially were used to parameterize the components of the turbulent diffusivity tensor. The values for the southern hemisphere were obtained by reflecting the northern hemispheric values, shifted by six months, and applying them appropriately in the southern hemisphere. However, when these transport coefficients were tested against the dispersion of inert tracers in the atmosphere, they were found to be not totally adequate [Widhopf (1975)] and were improved by numerical experimentation described by Widhopf, et al. [1977]. Additional tropospheric modifications which were necessary to model the water vapor distributions are discussed in subsequent sections. The most current values of the turbulent diffusion coefficients used in the model for the months of October, January, April, and July are also included in the Appendix.

The mean meridional circulation was obtained from the work of Louis, et al. [1974] who calculated the circulation patterns by solving the continuity and energy equations using compiled observations of the local meridional

temperature distributions and heat transfer rates. These are the same data sources used to define the thermal structure of the atmosphere, as previously discussed. The circulation patterns are specified for the entire meridional plane for each season from the surface to 50 km. In order to insure that total mass conservation was satisfied, the vertical wind component obtained by Louis was specified and the meridional component calculated from the global continuity equation. Both the vertical and meridional wind velocities are tabulated in the Appendix.

In order that smooth variations of all these parameters exist throughout the year, the temperature, density, and transport parameters (k_{zz}, $k_{\phi z}$, $k_{\phi\phi}$, and w) were specified at each location by temporarily fitting the data previously described using a five-term Fourier series.

6. NUMERICAL SCHEME

In this model, an accurate (second-order in space and time) and efficient time-implicit finite difference scheme has been employed to solve the governing individual species conservation equation for those species with chemical lifetimes less than two days [$O(^1D)$, $O(^3P)$, O_3, N, NO, NO_2, NO_3, N_2O_5, H, OH, HO_2, H_2O_2, Cl, ClO, and $ClONO_2$]. Advective and diffusive terms that are important in determining the time-dependent distributions of the species are treated using a leap-frog and a Dufort-Frankel finite difference scheme, respectively.

The time-implicit method makes use of a second-order accurate method developed by Widhopf and Victoria [1973]. In this method, the chemical production/loss term $\mathring{\omega}_i$, at a specific mesh point and at the new time level n+1, is approximated by the expansion

$$\mathring{\omega}_i^{n+1}(Y_i, \rho, T) = \mathring{\omega}_i^n + \sum_{i=1}^{N} \left(\frac{\partial \mathring{\omega}_i}{\partial Y_i}\right)^n \left(Y_i^{n+1} - Y_i^n\right) + \left(\frac{\partial \mathring{\omega}_i}{\partial \rho}\right)^n \left(\rho^{n+1} - \rho^n\right)$$

$$+ \left(\frac{\partial \mathring{\omega}_i}{\partial T}\right)^n \left(T^{n+1} - T^n\right) \qquad (2)$$

where the index i denotes the species i, Y_i the corresponding mass fraction, T the temperature, ρ the density, n the current time level of the computation, and N the number of species considered. All partial derivatives of $\mathring{\omega}_i$ are analytically computed and evaluated at the current time level n. In addition, $\mathring{\omega}_i^n$ is approximated by the following:

$$\mathring{\omega}_i^n = \frac{\mathring{\omega}_i^{n+1} + \mathring{\omega}_i^{n-1}}{2} .$$

The use of these relations in the governing species conservation equations results in a linear set of coupled equations for Y_i^{n+1}. (For this problem, the time variations of ρ and T are specified.) These equations are coupled only in time and not in space, and thus the technique results in a solution of a set of N_s linear equations at each mesh point. The stability and accuracy of the scheme is discussed by Widhopf and Victoria [1973].

This time-implicit algorithm overcomes the "stiff" nature of the governing equations which results from the wide range of chemical time scales of the problem. For the current numerical system, the allowable time step is determined by the convective time-step limitation, which yields a maximum time step of a few days. In order to simplify the calculation and reduce the N_s matrix size (with analogous reduction in computation time), only those species whose shortest chemical time scales are less than two days throughout the computational domain need to be solved using the time-implicit algorithm. All other long-lived species (N_2O, H_2O, HNO_3, CO, CH_4, and HCl) are solved in a straightforward explicit manner. This combination of numerical algorithms has proven to be computationally stable and accurate with a significant reduction in computation time. The simulation of one complete yearly cycle requires approximately 20 min on a CDC 7600 and includes all radiative flux calculations.

7. WATER VAPOR MODELING

Water vapor is the source of hydroperoxyls in the natural atmosphere and is also a major component of exhaust emissions from aircraft propulsion systems. These hydroperoxyls play an important role in determining the chemical state of the atmosphere as well as the effect of various pollutants on this natural state.

The simulation of the water vapor distribution in the atmosphere is difficult because it undergoes an exponential decrease in concentration in the troposphere from a surface value of approximately 10^4 ppmv to a relatively constant low concentration of approximately 4-6 ppmv in the stratosphere. The tropospheric distribution results from a balance between surface evaporation, rainout, and transport, whereas the stratospheric distribution depends on the gross transport exchange mechanisms between the troposphere and stratosphere, with chemistry playing a minor role. Because of limited knowledge of the controlling physical mechanisms in each of these areas, the distribution of H_2O has not been previously calculated in aeronomic photochemical models, but specified using data as a guide. As an example, Widhopf, et al. [1977] prescribed the water vapor distribution in the troposphere by specifying the relative humidity following the work of Manabe and Wetherald [1967], and the stratospheric value was assumed to be 2.5 ppmm as interpreted from the measurements of Mastenbrook [1971]. In addition to these modeling problems, early indirect measurements of the hydroperoxyl reaction rates indicated H_2O emission effects on O_3 were much less than the corresponding effect of NO_x on O_3. Thus, active modeling of water vapor was not emphasized.

However, due to the increased importance of tropospheric phenomena, as shown by the work of Widhopf, et al. [1977] and Hidalgo and Crutzen [1977], the active modeling of water vapor is now more important since it would provide a representation of rainout/washout phenomena which are important in the troposphere. Furthermore, new direct measurements by Howard and

Evenson [1977] and Zahniser and Howard [1978] of hydroperoxyl reaction rates for the reactions $NO + HO_2$ and $HO_2 + O_3$ (discussed in subsequent sections) have increased the magnitude of these rates by a factor of approximately 35 and 3, respectively. These rate changes have increased the importance of hydroperoxyls in the chemical balance of the natural and perturbed atmosphere.

In this regard, it is necessary to include an active water vapor model in any comprehensive atmospheric model. The very simple model used herein is a result of an extension of a one- and two-dimensional steady-state water vapor modeling effort described by Glatt and Widhopf [1978]. Here, the average rainout rate as a function of latitude [Junge (1963)] is used to describe the rainout in the troposphere. The rainout is treated as a first-order removal mechanism proportional to the local water vapor concentration and removed throughout the troposphere at the average precipitation rate interpreted from available data. The latitudinal variation of the local residence time, $a(\phi)(1/sec)$, as interpreted from Junge [1963], is presented in Table IV. The time-dependent surface boundary condition is a relative humidity specification using the work of Manabe and Wetherald [1967].

This is a very simple empirical approach somewhat consistent with this type of empirical photochemical model of the atmosphere. Other more complicated approaches were attempted; however, each required fundamental empirical or assumed information at some point. For example, rainout occurs when warm moist air accents and saturates; however, in the present model, the vertical velocities are prescribed in the mean and have no meaning when applied to the determination of a condition when rainout can occur. As a result, we have used this approach due to its simplicity and ease of interpretation of the consequences of the specification of empirical information. As will be shown, the model yields relatively adequate agreement with the sparse available H_2O data.

TABLE IV. LATITUDINAL VARIATION OF RAINOUT RATE PARAMETER $a(\phi)$ AS INTERPRETED FROM JUNGE [1963]

LATITUDE

	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°N
$a(\phi)(10^6/\mathrm{sec})$	1.76	1.36	1.1	1.2	1.79	2.08	1.89	1.2	0.90	0.83

Figures 1a through 1d show calculated water vapor profiles for the mid-months of each of the four seasons compared with available tropospheric data [Oort and Rasmussen (1971)] and data compilation by Harries [1976]. As can be seen, the exponential decrease of water vapor with increased altitude in the troposphere is calculated adequately, as is the average stratospheric concentration. In general, comparison with tropospheric data for all seasons shows relatively good agreement at the mid-latitude (30^{o}N). At the equator, the calculated concentration of water vapor above 5 km is higher than the data for all seasons, whereas at 60^{o}N the results are in good agreement during the spring and summer seasons, but low during the fall and winter. The underprediction at 60^{o}N is essentially due to the lower surface concentration used in the model. The higher values predicted at the equation above 5 km are due to the upward convection of moist air from the surface to higher altitude. This is due to the fact that upward motion exists in the equatorial region throughout the year, while the surface maintains a high concentration of water vapor. Considering the simplicity of the model, the results are encouraging.

In the present model, the water vapor distribution arises from a balance between a surface flux (evaporation), rainout, and transport, with chemistry playing a minor role. The surface flux F_z is given by $F_z(\varphi) = -\rho k_{zz} dY/dz \big|_{z=0}$, where ρ is the density, k_{zz} the vertical diffusion coefficient, and Y the mass fraction of water vapor. The total precipitation at the surface at any particular latitude is given by

$$P(\phi) = \int_{o}^{H(\phi)} a(\phi)\, \rho Y \, dz$$

where $a(\phi)$ is the average rainout rate constant (sec^{-1}) as a function of latitude, and H is the height of the troposphere. Figure 2 shows the latitudinal distribution of average annual precipitation compared with data [Junge (1963)].

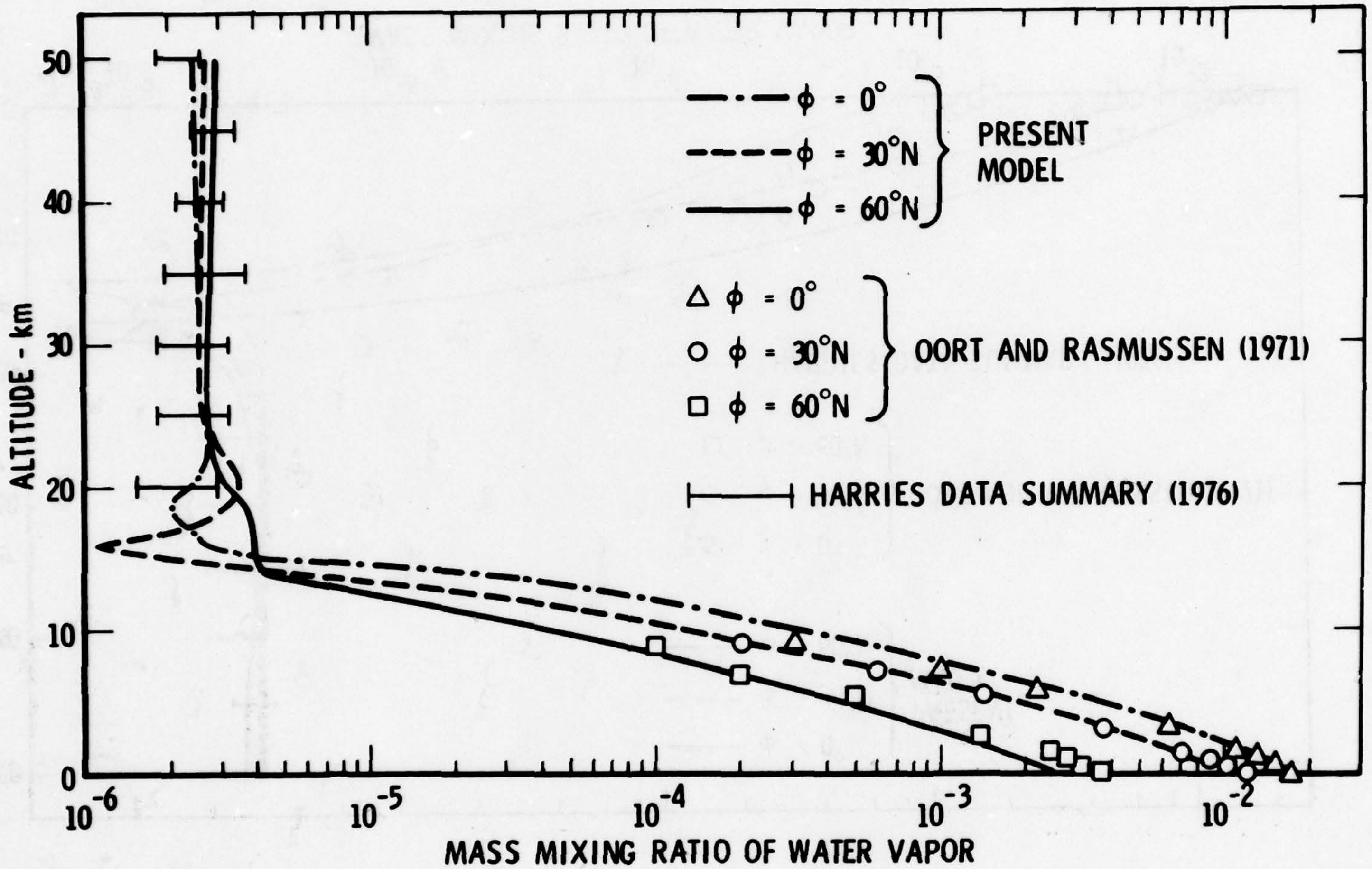

Fig. 1a. Water Vapor Profile in Natural Atmosphere in October

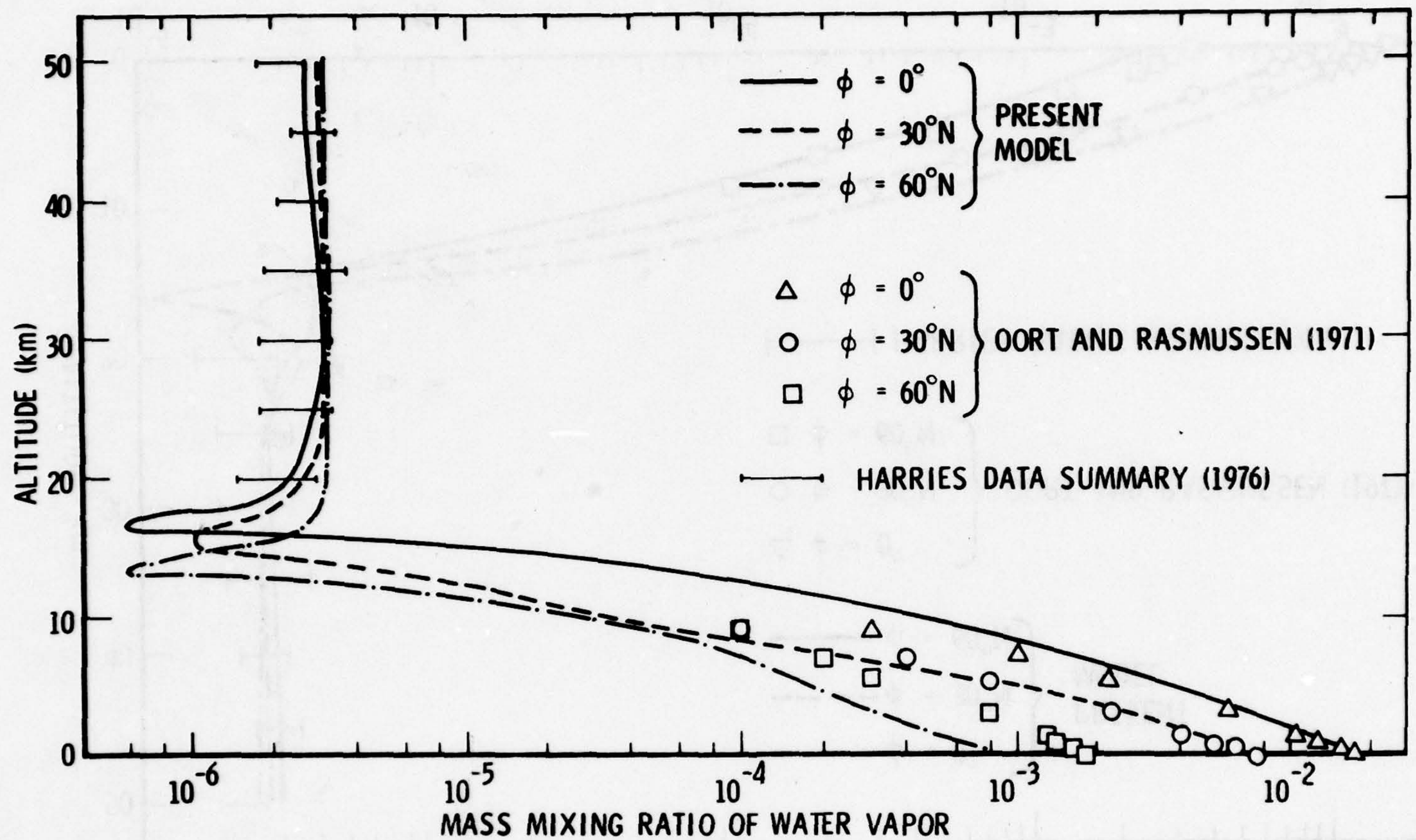

Fig. 1b. Water Vapor Profile in Natural Atmosphere in January

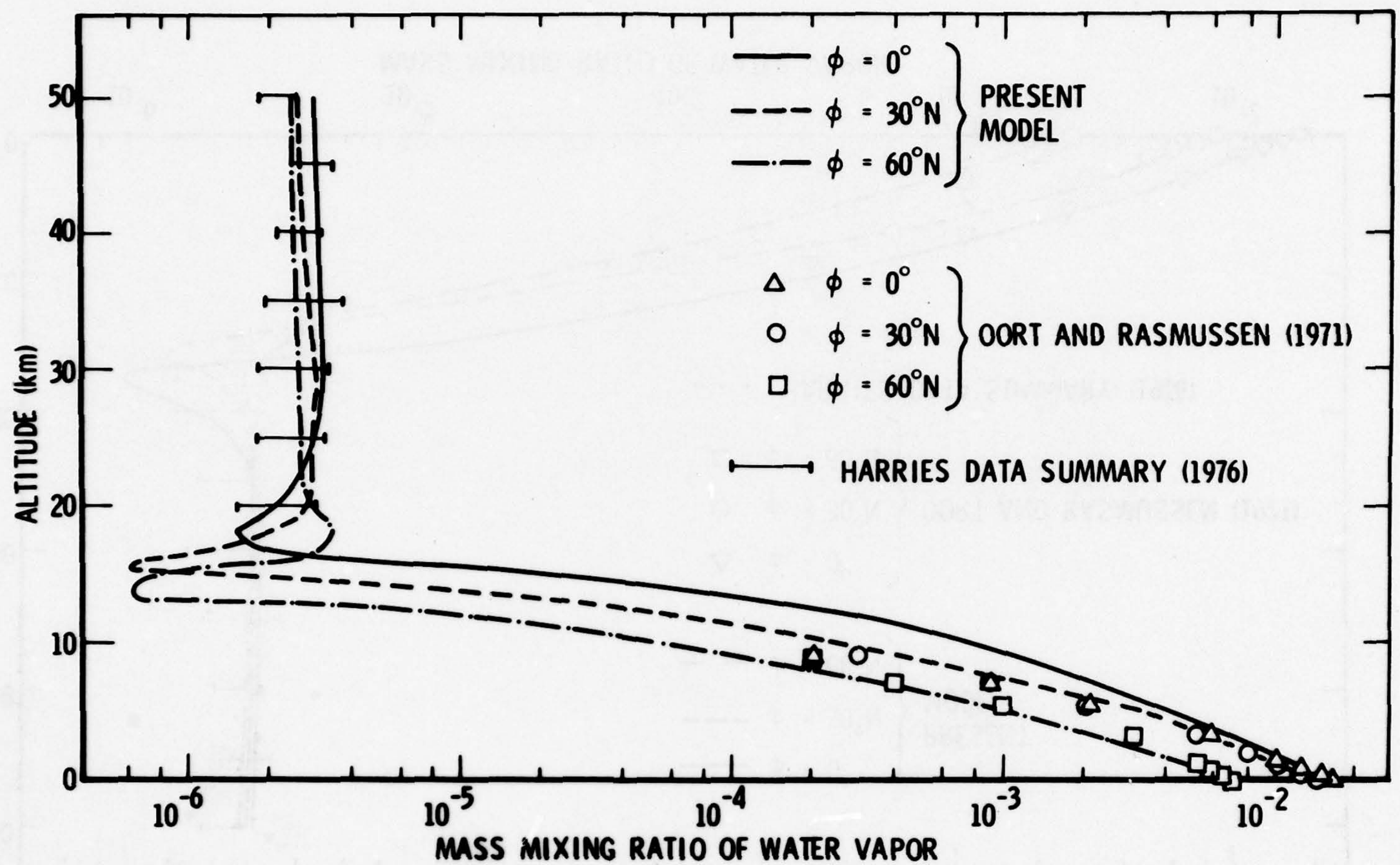

Fig. 1c. Water Vapor Profile in Natural Atmosphere in April

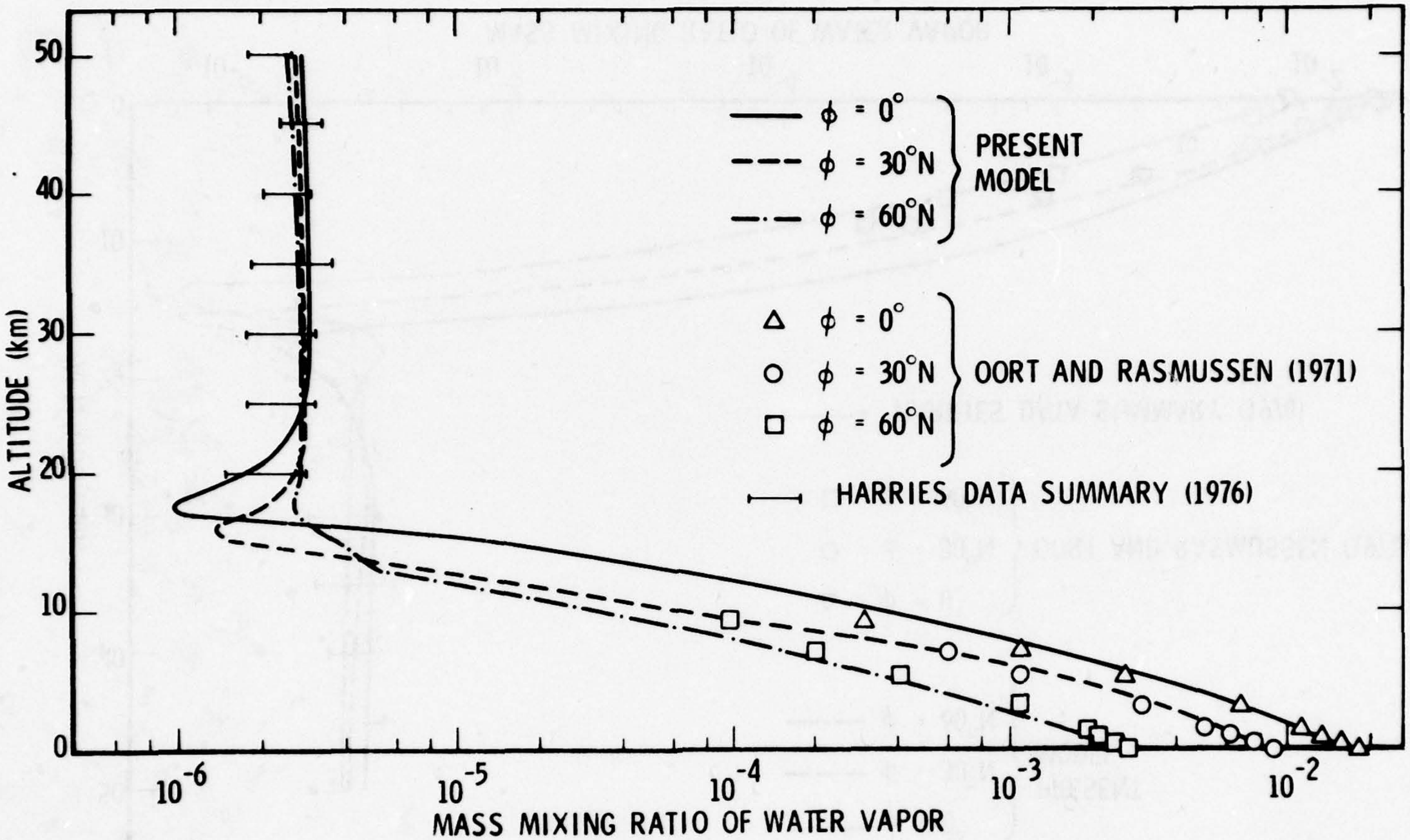

Fig. 1d. Water Vapor Profile in Natural Atmosphere in July

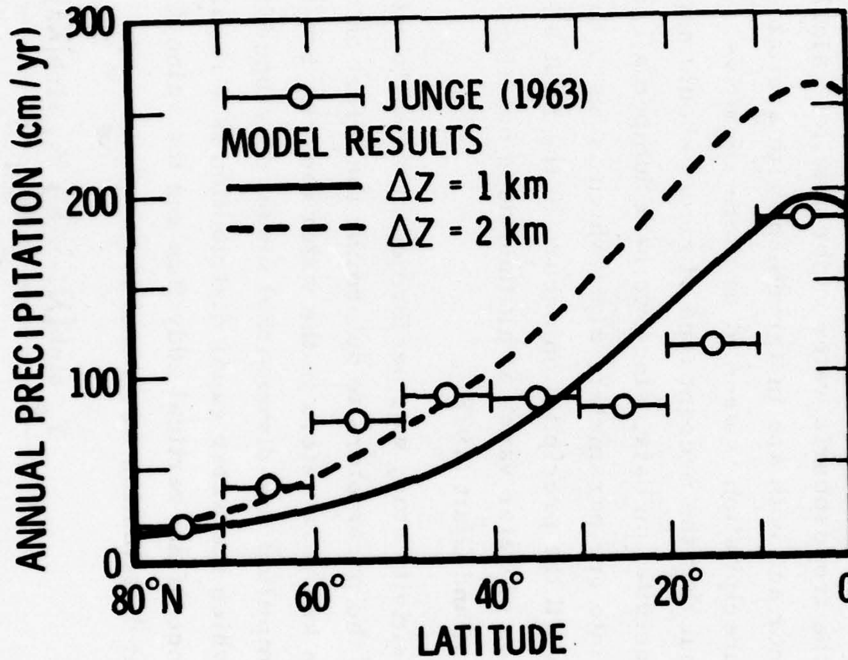

Fig. 2. Comparison of Measured and Calculated Average Annual Precipitation Rate

The resultant latitudinal distribution of precipitation, although high, does seem to follow the trends in the data between 0°N and 25°N. However, the results do not show the constant level of precipitation as measured between 25 and 55°. Also included is the latitudinal distribution of precipitation for an earlier calculation where the vertical resolution in the troposphere was 1 km. The differences in the two calculations result from relative changes in the first two km of the respective calculated water vapor profiles. The changes in the tropospheric water vapor profiles calculated with each resolution are minor and both are in agreement with available data; however, the calculated precipitation is seen to be more sensitive. In this regard, it must be pointed out that the present type of model should not be expected to reproduce the precipitation data, since we have lumped all the physical mechanisms for rainout into one parameter, $a(\phi)$, which is just a function of latitude. Since nearly all the precipitation occurs in the first 5 km in the model, the mass fraction of water vapor at altitude does not affect the total precipitation rate [Widhopf and Glatt (1978)].

A sensitivity study was performed in order to attempt a systematic variation of the parameters to determine the effect on the water profiles of changing the key parameters in the water model. From the results of the previous simplified one-dimensional model developed by Glatt and Widhopf [1978], in which the water vapor distribution is a result of a balance between the divergence of the vertical eddy flux and the rainout (i.e., precipitation), the resultant distribution was found to be

$$Y = \frac{Y_s \sinh[\bar{\lambda}(1-\bar{z})] + Y_H \sinh[\bar{\lambda}\bar{z}]}{\sinh \bar{\lambda}}$$

where Y_s is the surface value of mass mixing ratio of water vapor, Y_H the mass mixing ratio at the tropopause $\bar{Z} = Z/H$, H the height of the tropopause $\bar{\lambda} = H\sqrt{a_o/K_o}$, a_o the constant rainout rate, and K_o the constant vertical

turbulent diffusion coefficient. The surface flux can be obtained by differentiating the above expression and is given by

$$F_s = \sqrt{a_o K_o}\,[Y_s \tanh\lambda - Y_H/\sinh\lambda]$$

For typical values of the parameters, the surface flux can be expressed as

$$F_s \simeq \sqrt{a_o K_o}\, Y_s .$$

Thus, it can be seen for a given value of Y_s that the surface flux is proportional to $\sqrt{a_o K_o}$. By requiring the surface flux to take on appropriate values, we require $\sqrt{a_o K_o}$ to be constant. The equation for the mass mixing ratio can now be written in terms of either a_o or K_o, i.e.

$$\lambda = H\sqrt{a_o/K_o} = \frac{H}{K_o}\sqrt{a_o K_o} = \frac{H a_o}{\sqrt{a_o K_o}}$$

One can now vary the parameters in a systematic way to attempt to match the data. However, since data exist for the total average annual precipitation rates [Junge (1963)], whereas there is some uncertainty in K_o, it is appropriate to fix a_o and vary K_o. This type of sensitivity study was carried out in the two-dimensional model where K_o is the value of k_{zz} at the surface. It should be emphasized that in the two-dimensional model k_{zz} is not constant in the troposphere, but is a function of latitude, altitude, and time of year as shown in the Appendix. The net effect was a modification of the two-dimensional vertical turbulent diffusion coefficients in the lower regions of the troposphere, the results of which correspond to the profiles shown in Figs. 1a through 1d.

The sensitivity studies performed to date have shown a relative insensitivity of the troposphere profiles to most changes in other parameters such as ± 15 percent variation in these rainout rates and the surface value of k_{zz}.

However, there is a larger sensitivity in the predicted stratospheric level of H_2O to transport across the tropopause. The Junge rainout rates are average tropospheric values and, as long as these values are specified throughout the troposphere as a function of latitude, the stratospheric values of water vapor concentration fall within the measured variation. However, changes in this specification can result in large increases or decreases in H_2O in the stratosphere.

Since proper transport of water vapor in the lower regions of the troposphere necessitated some modifications to the turbulent diffusion coefficients, as well as providing a means for calculating the effect of washout, it was important to verify these coefficients by rerunning previous inert tracer experiments such as C-14, W-185, and Zr-95. In the case of W-185 and Zr-95, the rainout/washout model was used to wash out these particulate tracers. The C-14 and W-185 results presented in Widhopf, et al. [1977], which were in good agreement with data, were not appreciably affected; however, the time decay of the total Zr-95 burden could now be reproduced using a smaller density of 2 gm/cm^3 as compared to 6.4 gm/cm^3 used in past simulations (see Fig. 3). Utilization of a density of 6.4 gm/cm^3 assumed the particle to be entirely composed of tungsten, while a density of 2 gm/cm^3 assumes some hybrid form of the particle, more in line with estimates made by others. Thus, the water modeling has been an aid in developing a better prescription of the transport in the troposphere.

Further model improvements are anticipated in which the surface relative humidity boundary condition will be replaced by a specified surface mass mixing ratio as a function of time. This modification should improve the water vapor distribution at the higher latitudes during the fall and winter seasons. Some minor modifications in k_{zz} will most probably be required. The resultant minimum in the water vapor profiles near the tropopause, although seen in some data sets (Figs. 1a through 1d), can probably be attributed to an improper specification of the transport coefficients near the tropopause, as well as the prescription of the manner in which the model parameter $a(\phi)$ approaches zero in the tropopause. The availability of more data and further analysis of our rainout and transport specification may lead to improvements in this area.

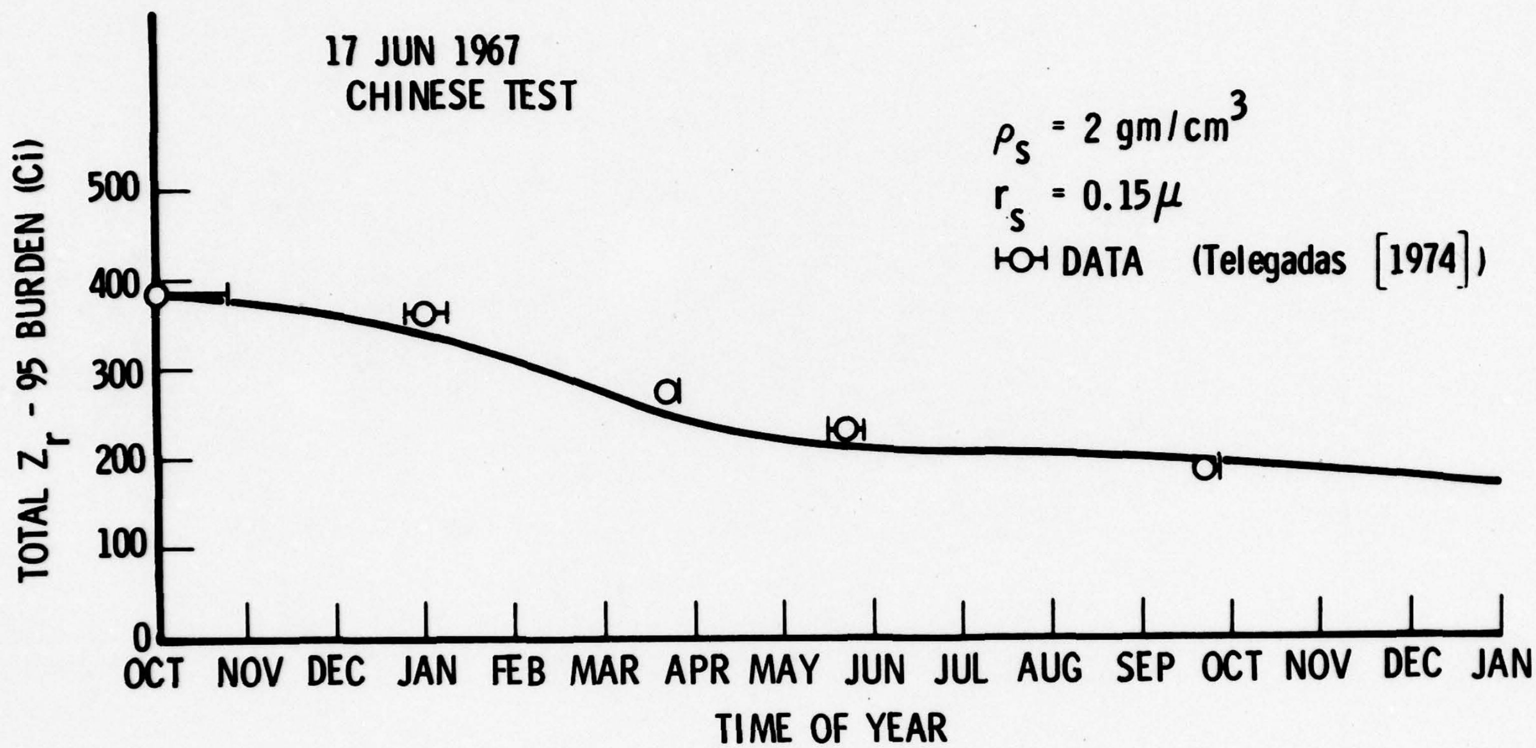

Fig. 3. Comparison of the Calculated and Observed Decay of the Z_r - 95 Burden Resulting from the 17 June 1967 Chinese Nuclear Test

8. MODEL RESULTS

In the last few years, the development and application of new laboratory techniques have resulted in the first direct measurements of some important hydroperoxyl reaction rates. These newly measured rates are significantly different in magnitude than those previously interpreted by indirect means. This has resulted in significant changes in the calculated distribution of some trace species in the natural and perturbed atmosphere, as well as an increase in the relative importance of the hydroperoxyl chemical cycle in aeronomic studies. These effects were investigated as an integral part of our continuing model development and study effort for HAPP, and the important changes are summarized herein, together with other model results.

In order to provide a frame of reference, model calculations performed using the O-H-N chemistry listed in Table I, and reported by Widhopf, et al. [1977], are reproduced in this report. These results were in good agreement with observations of O_3 for both total ozone column and the spatial distribution of ozone using the chemical reactions and rates accepted to be most accurate at the time (1976). In these calculations, H_2O was specified and NO_3, N_2O_5, and ClO_x were not considered. In addition, a straightforward diurnal averaging procedure was used. The variation of the calculated ozone column in the natural atmosphere with time of year is reproduced in Fig. 4a, which can be compared to Dütsch's [1971] compilation of observed ozone data (see Fig. 4b). The calculation is in good agreement with observations except at high latitudes during the winter-spring seasons where the ozone column is underestimated by, at most, 9 percent. Ozone profiles calculated at various latitudes during the mid-months of each season are reproduced in Figs. 5a through 5d, together with available data. The calculated profiles reproduce the observed distributions throughout the year except in the troposphere, where the O_3 levels are underpredicted.

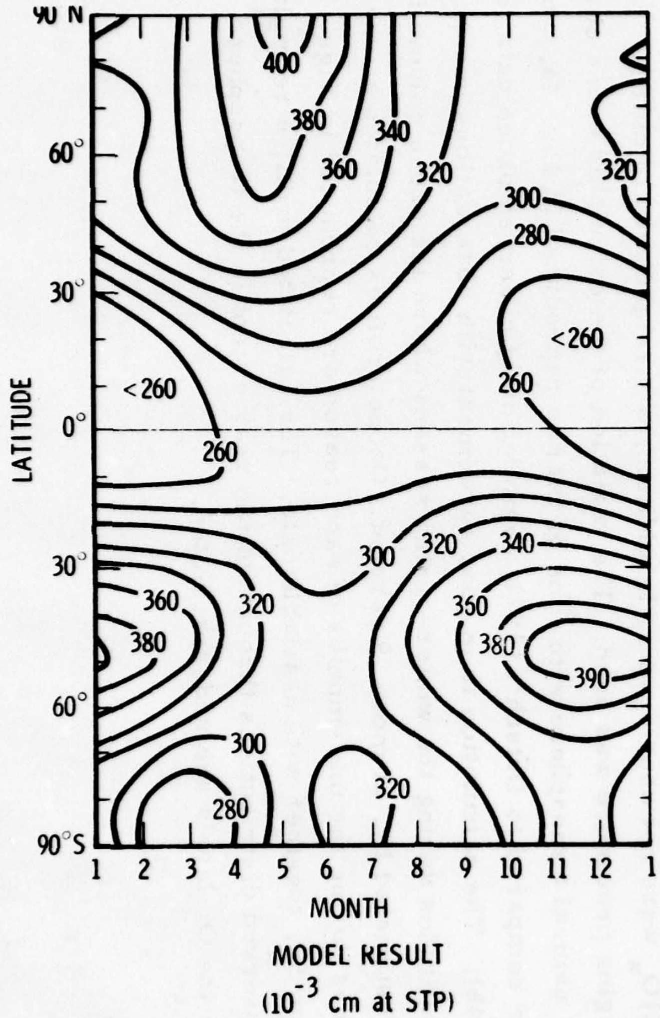

Fig. 4a. Calculated Monthly Variation of the Total Ozone Column as a Function of Latitude (10^{-3} cm at STP) Using Chemical System Outlined in Table I. (After Widhoff, et al (1977)]

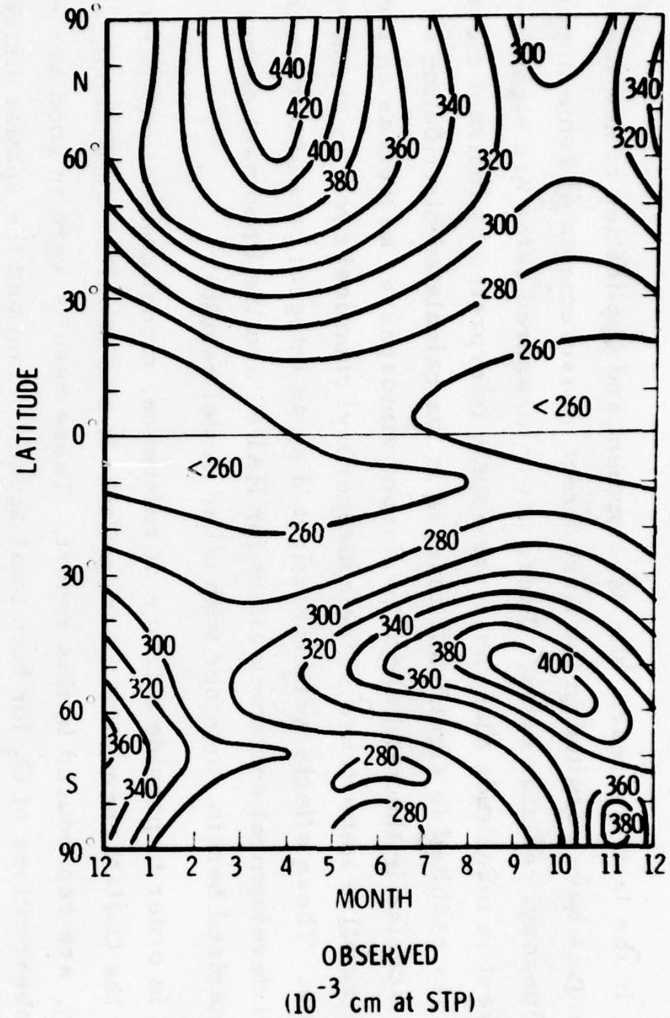

Fig. 4b. Observed Monthly Variation of the Total Ozone Column as a Function of Latitude (10^{-3} cm at STP) [After Dütsch (1971)]

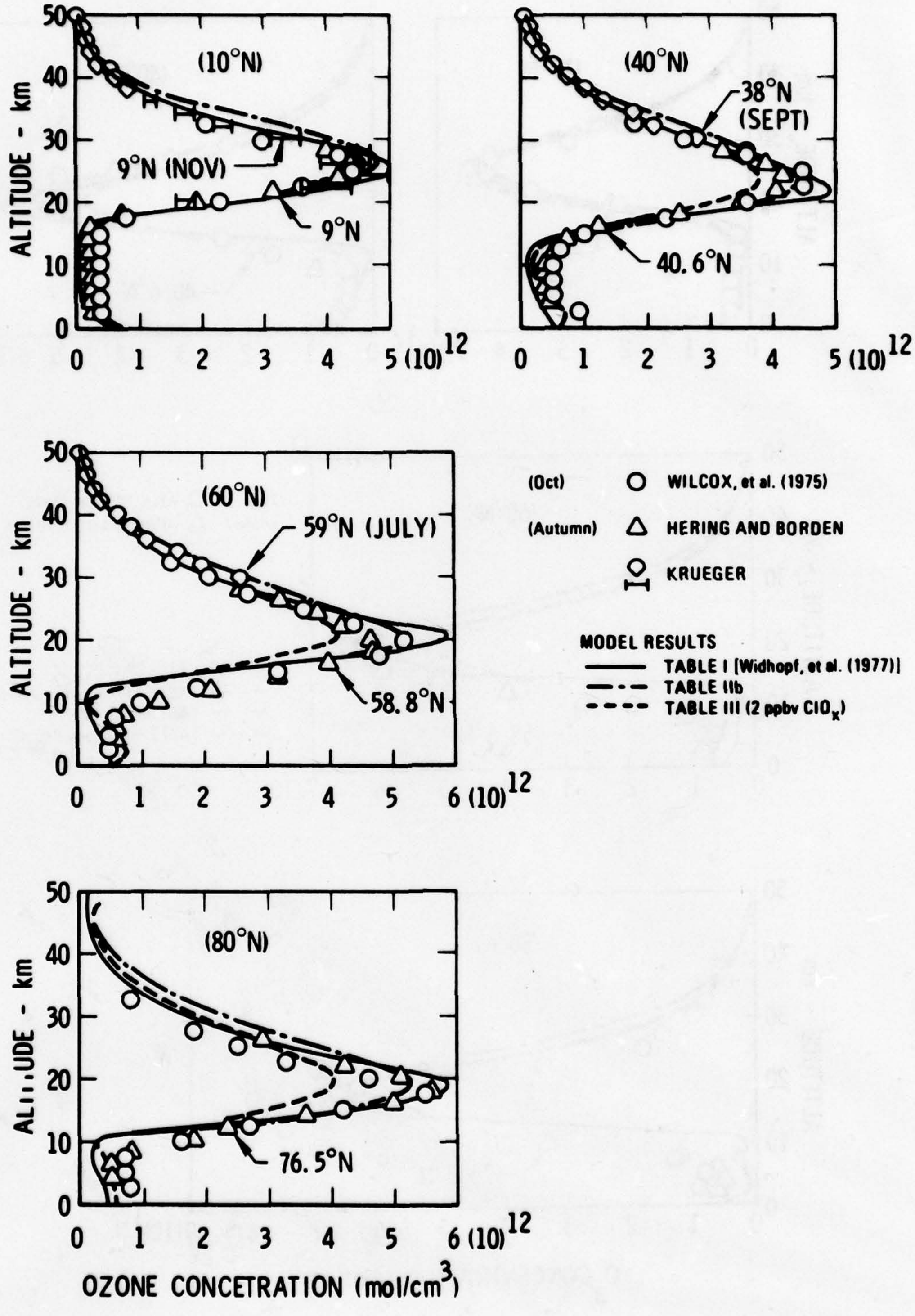

Fig. 5a. Comparison of Calculated and Observed Ozone Profiles

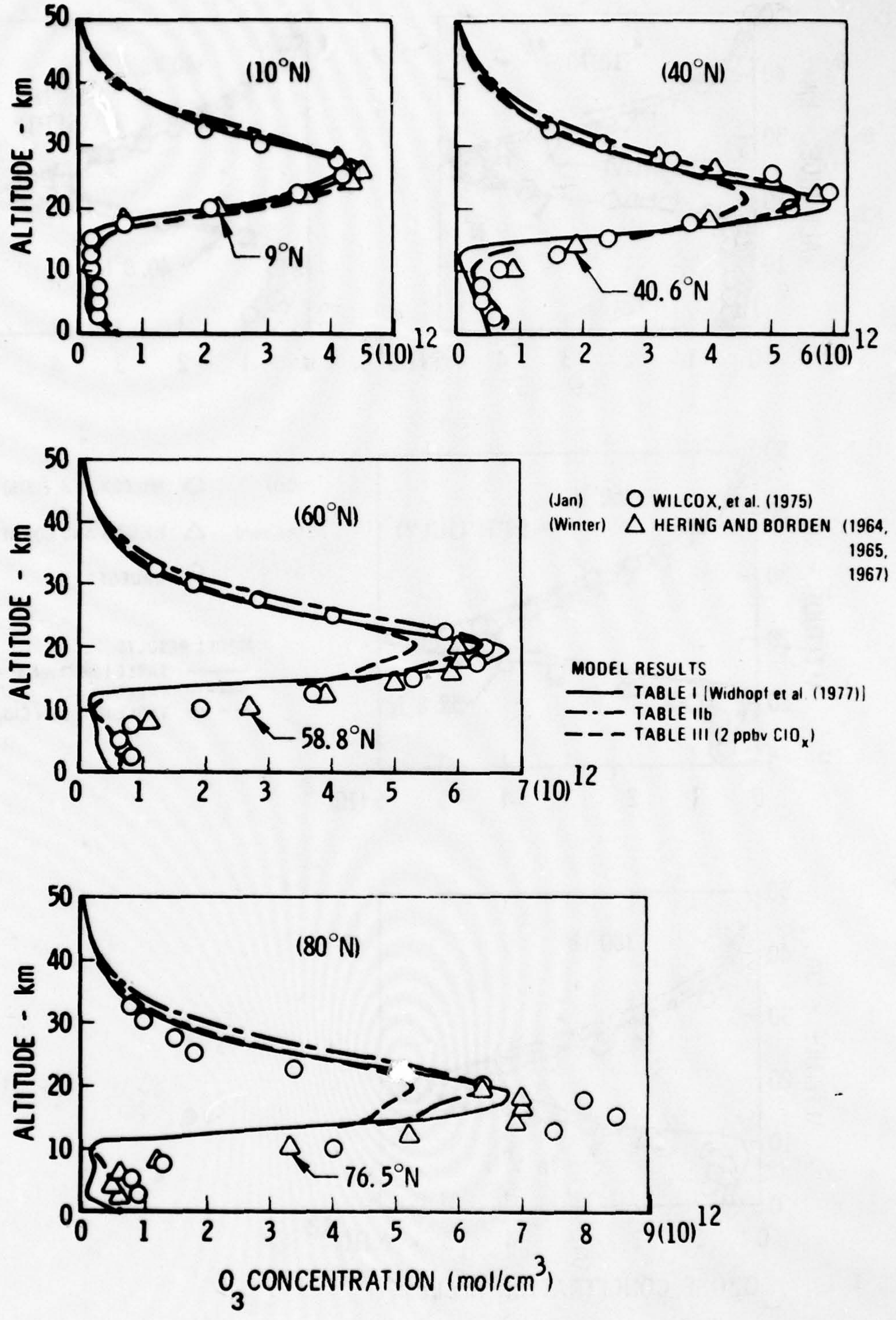

Fig. 5b. Comparison of Calculated and Observed Ozone Profiles

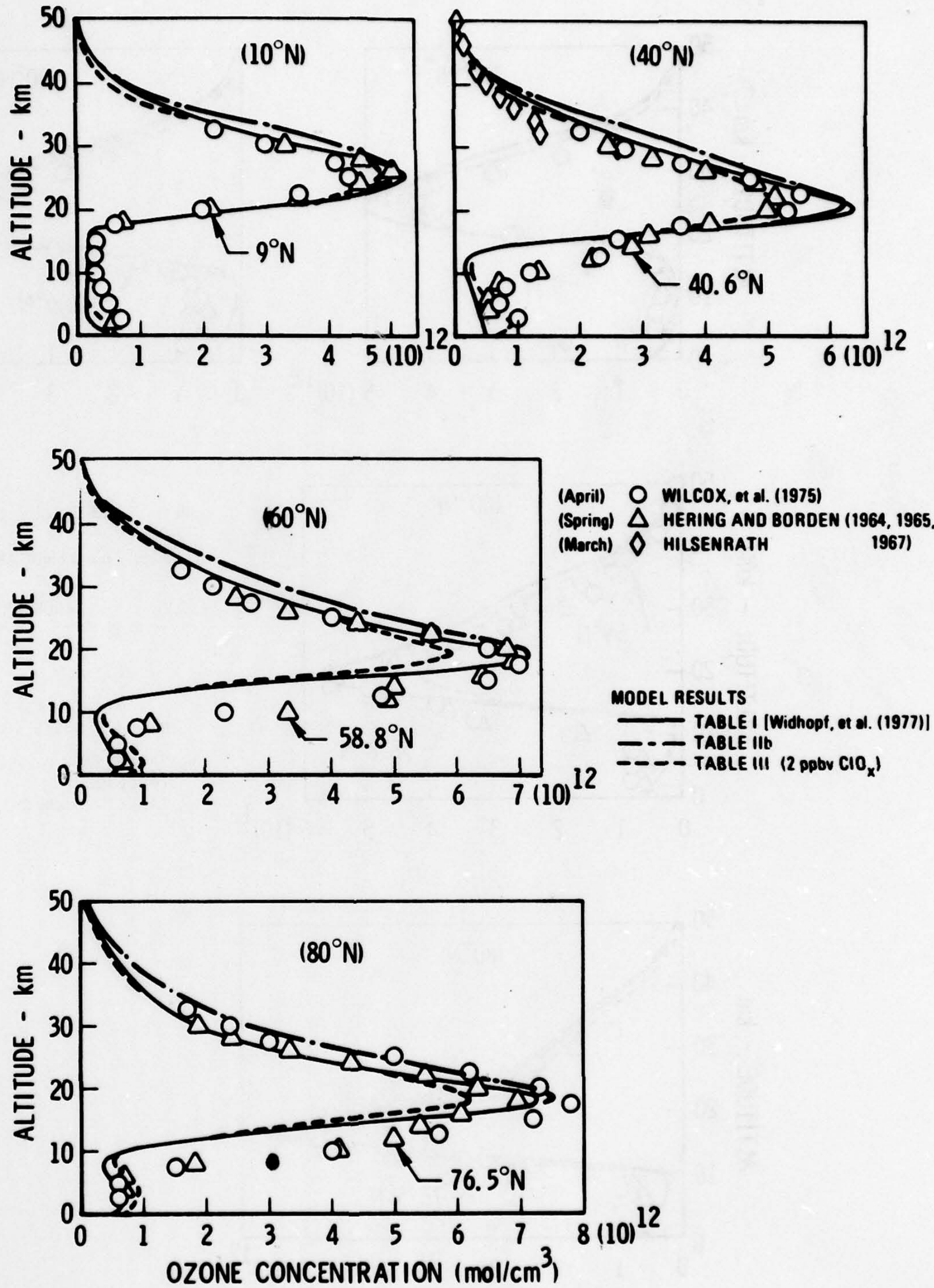

Fig. 5c. Comparison of Calculated and Observed Ozone Profiles

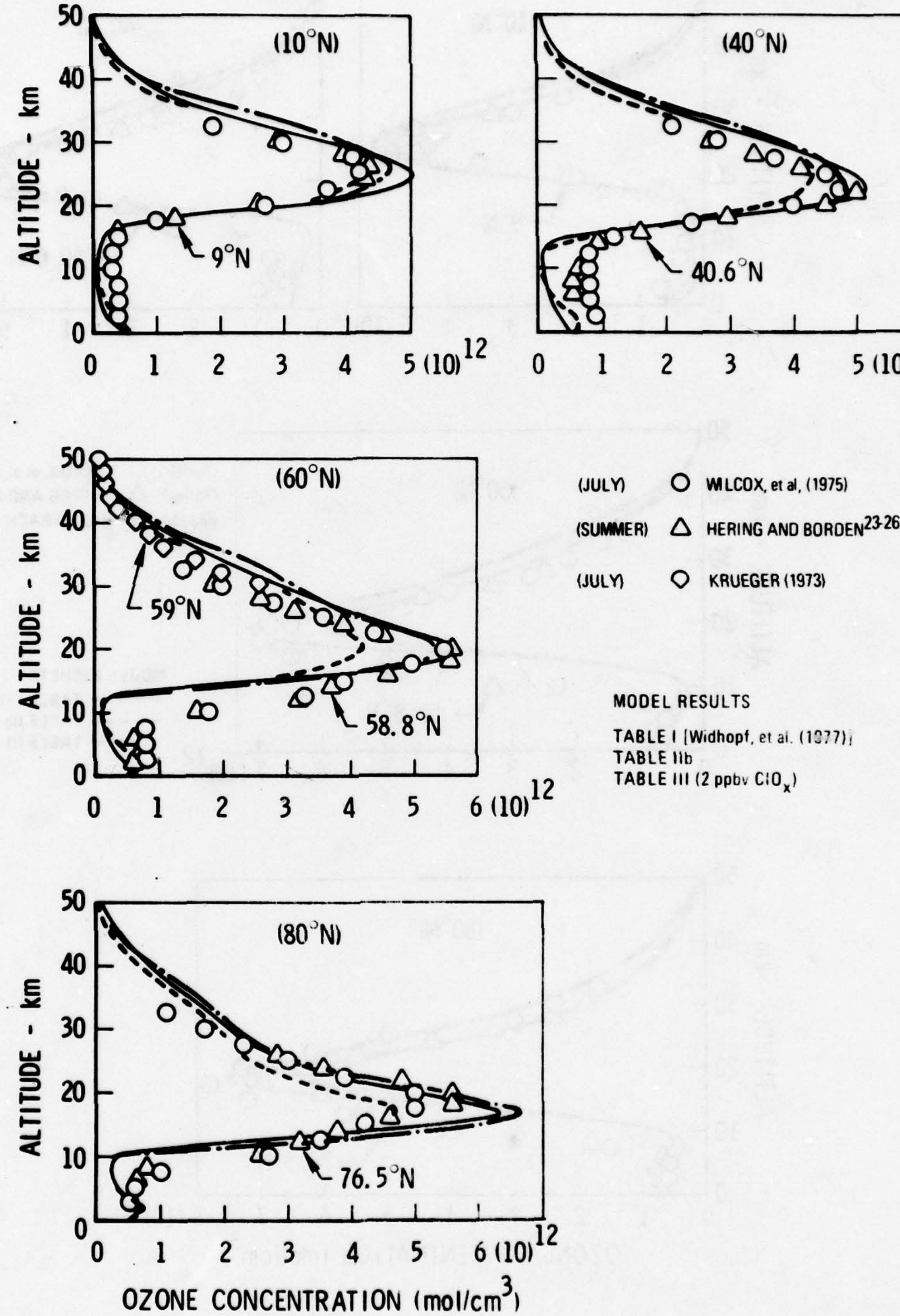

Fig. 5d. Comparison of Calculated and Observed Ozone Profiles

Subsequent calculations of the effect on ozone abundance of projected 1990 subsonic and supersonic fleet NO_x emissions (see Table V), which were performed in that same study, indicated a potentially small overall increase in ozone due to these emissions. Specifically, the calculations indicated that NO_x emissions in the troposphere from subsonic-type aircraft could result in an O_3 increase through the "smog" chemical cycle as opposed to an O_3 column decrease above approximately 15 km resulting from supersonic aircraft NO_x emissions in the stratosphere. Representative results are reproduced in Figs. 6a, 6b, and 7 which depict the ozone column change at various latitudes over five years of simulation and also show the latitudinal variation during the fifth year at February 15, June 15, and October 15. A typical change in the O_3 concentration with altitude at $40^{\circ}N$ during October is shown in Fig. 8, where the ozone concentration change is shown to be negative above approximately 21 km and positive below. This results in an overall column increase below ~15 km. A more detailed explanation of the important chemical mechanisms in each regime is included in Widhopf, et al. [1977].

As a consequence of these results, subsequent modeling efforts were initially focused on modeling H_2O, since any information in this area would (a) provide a better evaluation than that used in the 1976 study of average rainout/washout effects which are important in the troposphere and influence the distributions of NO_x and HO_x, (b) provide the ability (heretofore unavailable) to actively model H_2O emissions which are a significant fraction of aircraft emissions, and (c) result in a better tropospheric model and prescription of the distribution of hydroperoxyls in the natural atmosphere.

As previously stated, important hydroperoxyl reaction rates were subsequently measured directly for the first time and became available during this effort. These new measurements were substantially different than the values listed in Table I and increased the relative importance of HO_x with respect to the effect of NO_x on O_3, making a water model even more important. Unfortunately for the modeler, not one but a number of hydroperoxyl reaction

TABLE V. 1990 WORLDWIDE AIRCRAFT NO_x EMISSIONS, HIGH ESTIMATES, kg/yr*

	ALTITUDES - km												
Latitude	6-8	8-9	9-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19	Total
N 60+	3.35E6	3.03E6	1.43E7	1.31E7	1.46E7	1.31E6	9.99E5	4.06E5	1.72E6	2.59E6	2.10E6	1.43E6	5.894E7
50-60	2.15E7	2.59E7	9.44E7	1.06E8	9.09E7	8.26E6	3.72E6	2.12E6	6.57E6	1.03E7	8.06E6	3.71E6	3.814E8
40-50	7.60E7	8.70E7	1.79E8	2.79E8	1.62E8	2.48E7	4.59E6	2.09E6	4.17E6	6.96E6	5.46E6	2.36E6	8.334E8
30-40	7.74E7	9.20E7	1.67E8	3.09E8	1.72E8	2.97E7	3.11E6	1.74E6	1.30E6	2.73E6	2.07E6	8.63E5	8.589E8
20-30	2.61E7	2.83E7	6.74E7	1.02E8	6.92E7	8.73E6	1.55E6	1.20E6	8.06E5	1.90E6	1.71E6	4.67E5	3.094E8
10-20	1.11E7	1.18E7	2.65E7	4.28E7	3.99E7	3.67E6	4.74E5	1.54E5	3.24E5	5.38E5	4.22E5	1.71E5	1.379E8
0-10	4.80E6	5.14E6	1.50E7	1.82E7	1.36E7	1.26E6	1.73E5	0	2.91E5	4.08E5	3.44E5	1.63E5	5.938E7
10-0	3.31E6	3.77E6	1.22E7	1.38E7	1.09E7	8.65E5	1.38E5	0	3.01E5	4.22E5	3.56E5	1.65E5	4.623E7
20-10	2.74E6	3.21E6	1.14E7	1.52E7	1.15E7	1.11E6	3.15E5	1.32E5	1.10E5	2.19E5	1.58E5	7.52E4	4.617E7
30-20	3.67E6	4.01E6	9.47E6	1.37E7	8.66E6	9.31E5	5.10E4	0	9.85E4	1.38E5	1.16E5	6.63E4	4.091E7
40-30	4.01E6	4.63E6	6.62E6	1.18E7	6.14E6	1.21E6	8.64E4	5.16E4	1.56E4	4.74E4	2.84E4	6.22E3	3.464E7
50-40	2.36E5	3.05E5	3.19E5	8.28E5	4.46E5	9.29E4	1.5 E1	0	0	0	0	0	2.227E6
60-50	4.77E4	3.79E4	2.99E4	2.52E4	1.04E4	1.45E3	0.97	0	0	0	0	0	1.526E5
S 60+	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	2.343E8	2.691E8	6.036E8	9.255E8	5.999E8	8.197E7	1.521E7	7.894E6	1.571E7	2.625E7	2.082E7	9.477E6	2.810E9

*Oliver, R.C. [1977] and Little, A.D. [1976]

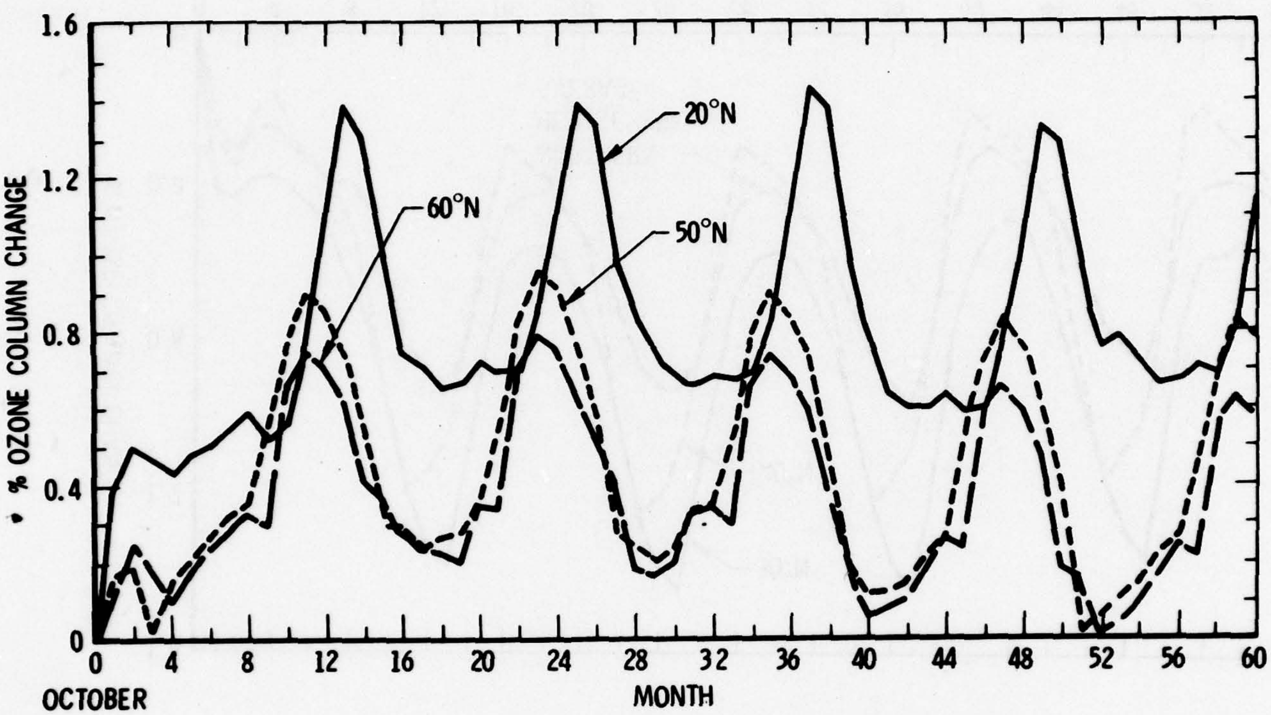

Fig. 6a. Calculated Temporal Ozone Change Resulting from Aircraft NO_x Emissions from a Combined Subsonic and Supersonic Fleet Projected to be Operational in 1990 Using Chemical System of Table I [after Widhopf, et al (1977)]

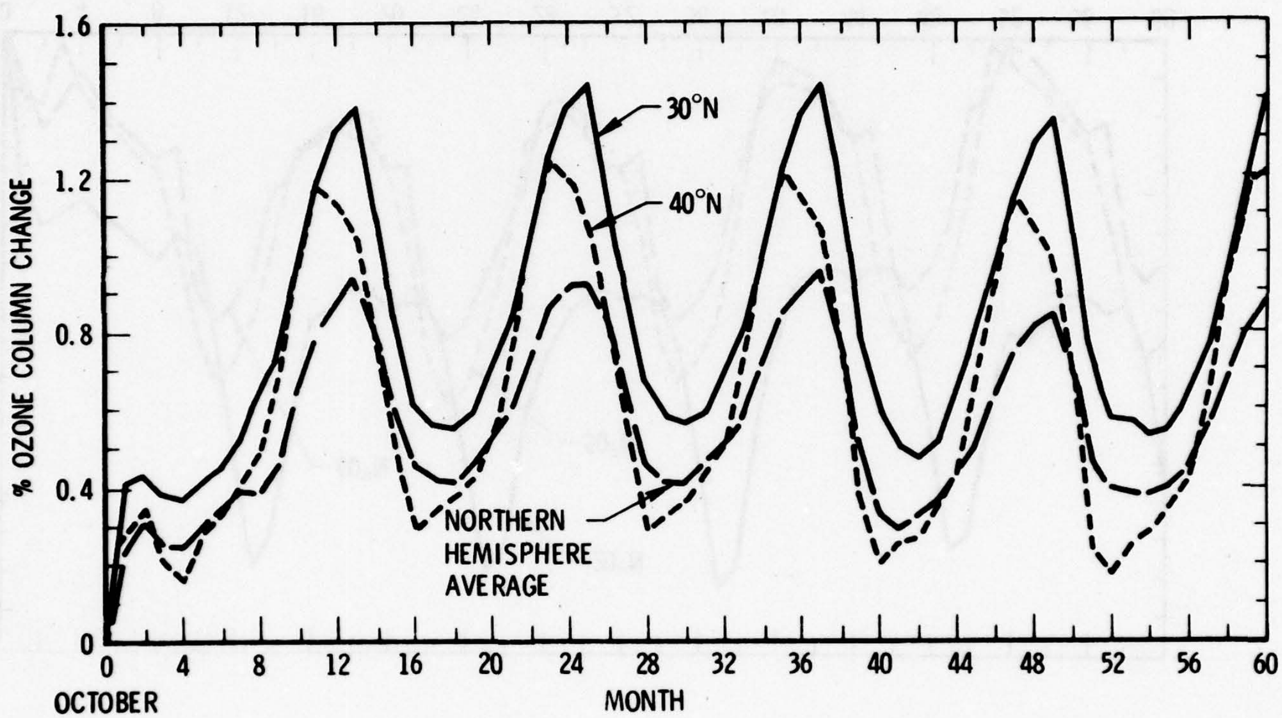

Fig. 6b. Calculated Temporal Ozone Change Resulting from Aircraft NO Emissions from a Combined Subsonic and Supersonic Fleet Projected to be Operational in 1990 Using Chemical System of Table I [after Widhopf, et al (1977)]

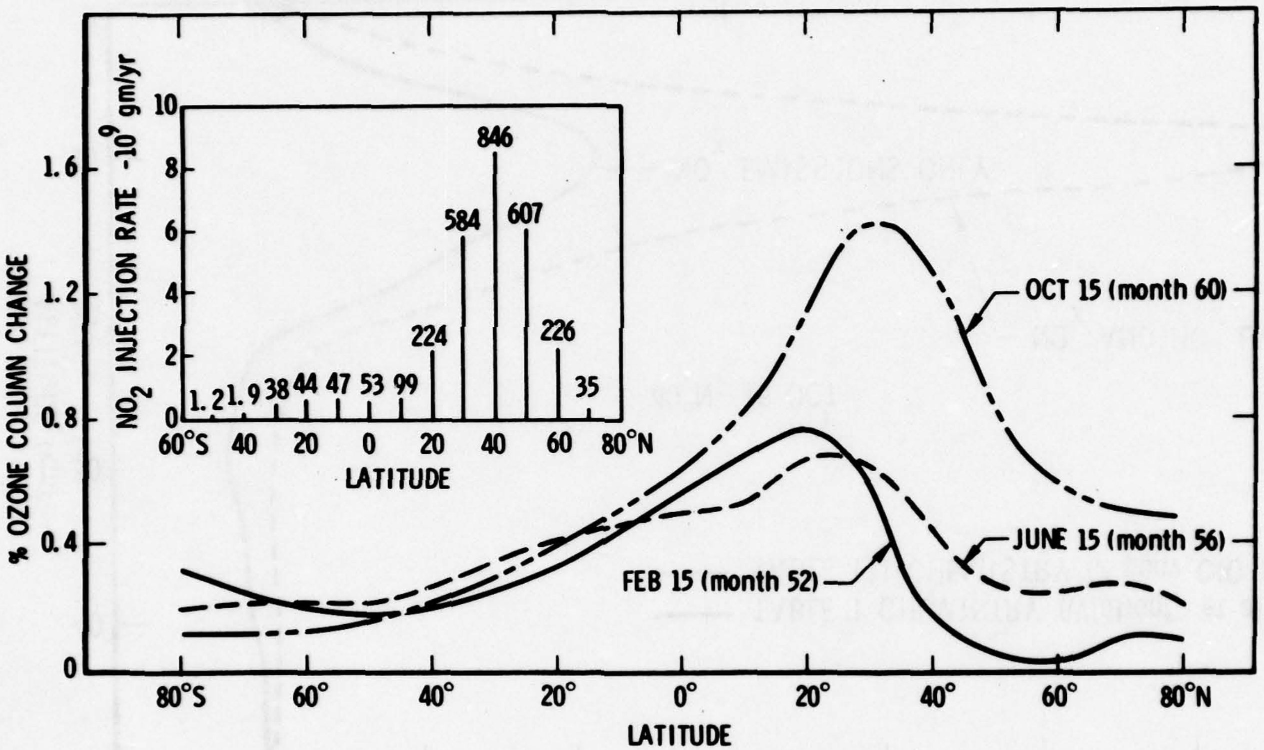

Fig. 7. Latitudinal Variation of Ozone Column Change (Table I. Chemical System (after Widhopf, et al 1977)

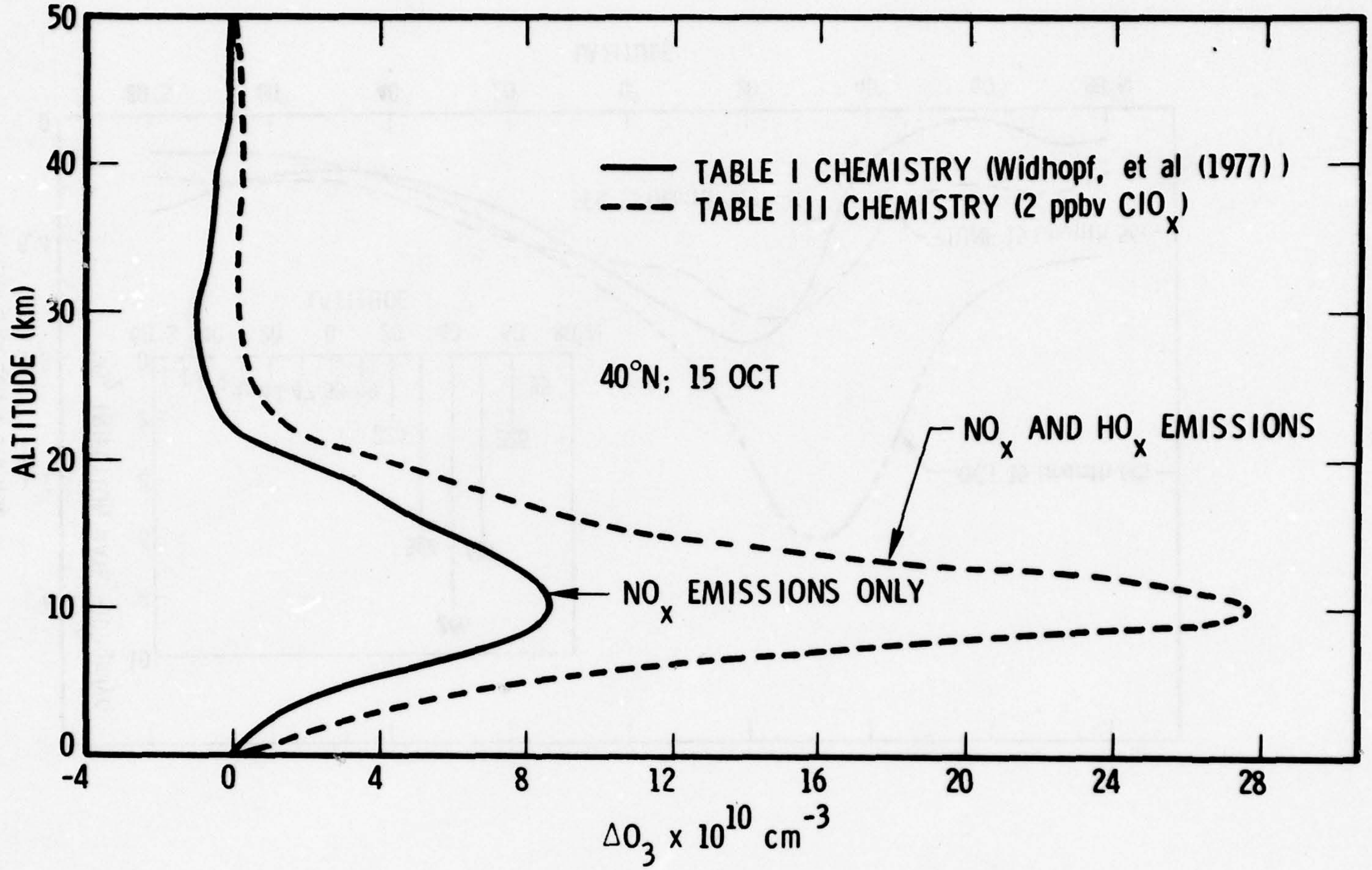

Fig. 8. Vertical Change in Ozone Concentration at 40° N During October Resulting from Aircraft Fleet Emissions Listed in Table V

rates have turned out to be incorrect; however, the measurements were necessarily made in sequence. This situation produced interim results when each measurement was reported which were not satisfying when compared to available ozone data. Thus, these interim results had to be investigated carefully, and the important findings are described in the following subsections.

8.1 NO + HO_2 (R10) RATE CHANGE

The rate at which the reaction $NO + HO_2 \rightarrow NO_2 + OH$ proceeds was measured by Howard and Evenson [1977] to be approximately 35 times faster than previously interpreted using indirect measurements (Table I). As a result, calculations were performed using this new NO + HO_2 rate ($R10 = 810^{-12}$) together with the updated reaction rates recommended in the NASA-CFM study [1977]. The rate R20 was also scaled appropriately as a result of this measurement, since this reaction rate was previously estimated using the same indirect methodology. The ClO_x was not considered in this computation; however, N_2O_5, NO_3, and active H_2O modeling were included, together with a day-night averaging needed to model the important nighttime chemistry of N_2O_5 and NO_3. The corresponding calculated results for the variation of the ozone column as a function of latitude and time of year in the natural atmosphere, originally reported by Widhopf and Glatt [1978], are shown in Fig. 9. The contours are similar to those shown in Figs. 4a and 4b; however, the ozone level is seen to be approximately 20 to 30 percent higher than either that measured or calculated with the old rate. The corresponding ozone profiles for various latitudes and seasons for this calculation are shown in Figs. 5a through 5d. These differences are primarily due to the increase in the NO + HO_2 reaction rate which results in, among other things, the increased conversion of NO into NO_2, an increase in production of $O(^3P)$, and the increased production of the NO_x sink, HNO_3. Since NO_2 is much less effective than NO in catalytically reducing ozone, as well as producing more $O(^3P)$, and since more NO_x is stored in HNO_3, this reaction rate change has resulted in an overall increase in ozone in the calculated natural atmosphere.

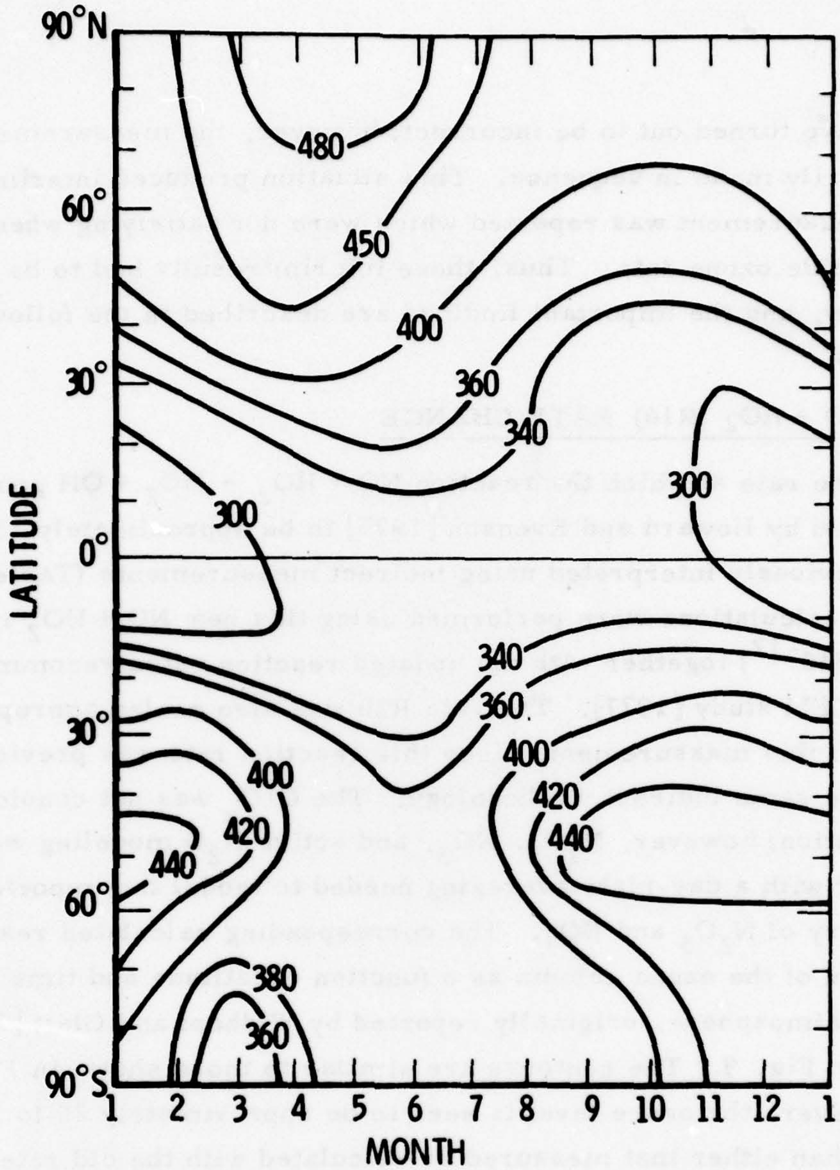

Fig. 9. Calculated Monthly Variation of the Total Ozone Column as a Function of Latitude Using Chemical System as Modified by Table IIa (10^{-3} cm at STP) [after Widhopf and Glatt (1978)]

Note that in this calculation the vertical transport above 20 km was reduced from that used in the previously described natural atmosphere calculation [Widhopf, et al. (1977)]. This change was introduced in order to reduce the levels of N_2O and CH_4 at altitude so that better agreement with available high altitude measurements of N_2O and CH_4 could be obtained. This change was determined not to affect any of the previous inert tracer results, since for these cases the major portion of the tracer was always below 25 km. This transport modification reduced the ozone overprediction to the present level of 20 to 30 percent.

At this point, some sensitivity studies were performed to determine if modifications to the transport could account for the discrepancy between the predicted and observed ozone columns. In brief, even relatively drastic changes in transport (while always trying to match observations of other species and inert tracers) could not account for the differences. Note here that the difference between measured and calculated ozone profiles is much more easily determined in a multidimensional model, since the measured profiles are available at various latitudes. In a one-dimensional model, the variation of a mean ozone profile is large because of the latitudinal variation of ozone and, thus, rather large changes in the calculated ozone profiles can still fall within the measured variation. This is not generally true in the multidimensional model case, and the comparisons are more direct. Further reduction of the vertical transport did not seem possible if the model results for other species distributions at high altitudes were to agree with available measurements (specifically N_2O and CH_4). As a consequence, the results of these numerical simulations indicated that another chemical rate could also be inaccurate, or an additional important chemical mechanism (perhaps involving HO_2NO_2) was not presently included in the model. The reader should not be left with the idea that we feel that the transport as prescribed in this model is quite correct but, rather, we consider that within our experience and the confines of our model tests these discrepancies in ozone cannot be accounted for by an inaccurate specification of the transport only. From our studies we believe that the discrepancy in this case must be principally

caused by a chemical problem, with the transport also playing a role. These questions were actively pursued and candidate reactions were suggested [Widhopf and Glatt (1978)], as interpreted from the results of both the natural atmospheric simulation and a study of the effect of combined NO_x and HO_x aircraft emissions on ozone.

In order to estimate the effect of combined NO_x and HO_x aircraft emissions, a calculation was performed injecting NO_x at the rate specified in Table V with the following modification: the rate of injection above 15 km was tripled. This effectively triples the number of supersonic aircraft considered. The HO_x was simultaneously injected at a rate 73.5 times the NO_x rate, which corresponds to the ratio of the HO_x to NO_x emission indices [Oliver (1976)]. The results of this calculation are shown in Fig. 10. For this case, the injection of combined NO_x and HO_x emissions increased the ozone concentration above the level calculated in the natural atmosphere in both the troposphere and stratosphere. Very small increases in ozone occur in the stratosphere with the predominant changes occurring in the troposphere where most of the pollutants are deposited. The resultant maximum increase in ozone column is approximately 3.5 percent, somewhat higher than the 1.5 percent obtained in the previous calculations where HO_x was not injected. This change was primarily due to the change in reaction rate 10. The variation with time of year is quite similar to the previous calculation in which the minimum effect occurs during late winter-early spring, and the maximum effect occurs during late summer-early autumn. This calculation was carried out for approximately two years since, as in the previous NO_x case, the overall column changes are nearly periodic from year to year after one-half year.

In order to understand and explain the increase in total ozone column obtained for this calculation, the chemical mechanisms for the production/depletion of ozone were investigated. Analyses of the results indicate that

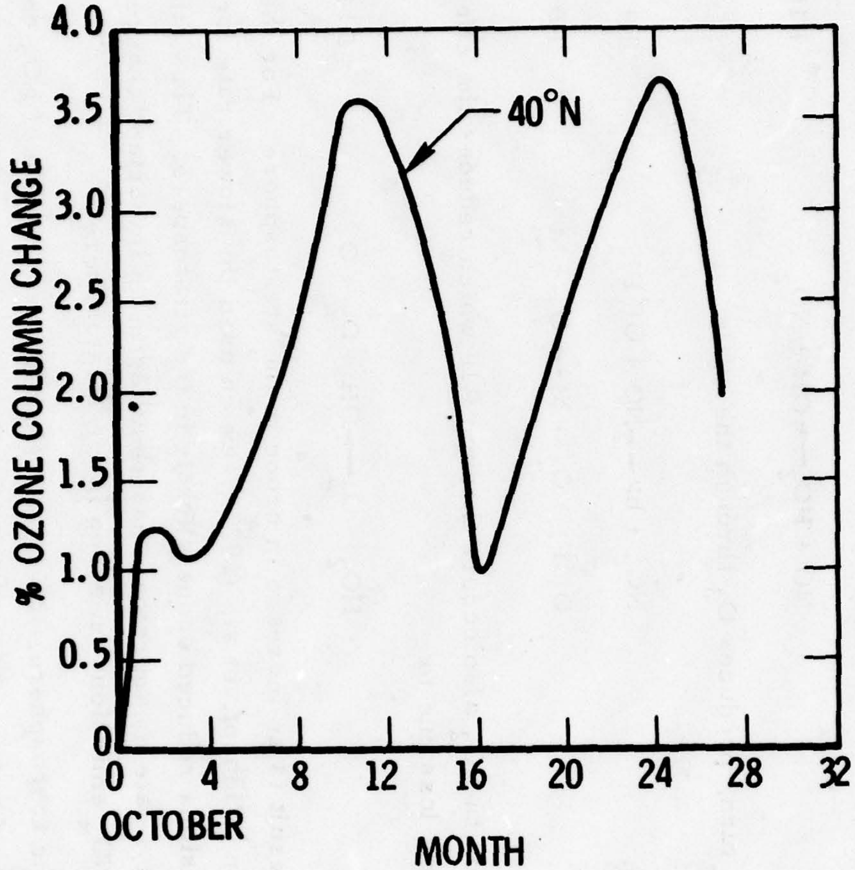

Fig. 10. Calculated Temporal Ozone Change Resulting from NO_x and HO_x Emissions from a Combined Subsonic and Supersonic Fleet of Aircraft Using Chemical System of Table IIa [after Widhopf and Glatt (1978)]

different chemical mechanisms are important in the stratosphere and troposphere. In the stratosphere, the injection of NO_2 depletes ozone through the catalytic destruction cycle.

$$NO_2 + O(^3P) \longrightarrow NO + O_2 \qquad R6$$

$$NO + O_3 \longrightarrow NO_2 + O_2 \qquad R7$$

However, the overall increase in ozone level is due to NO reacting with HO_2, i.e.

$$NO + HO_2 \longrightarrow OH + NO_2 \qquad R10$$

which, in turn, produces O_3 through the cycle

$$NO_2 + h\nu \longrightarrow NO + O(^3P) \qquad R4$$

$$O(^3P) + O_2 + M \longrightarrow O_3 + M \qquad R5$$

A reduction in HO_2 also occurs through R10 which reduces the effectiveness of the ozone loss due to

$$HO_2 + O_3 \longrightarrow OH + O_2 + O_2 \qquad R14$$

The net result is an increase in ozone in the stratosphere. For the previous calculation [Widhopf, et al. (1977)], which used the slower rate for R10, the NO_x emissions reduced ozone slightly in the stratospere. Thus, this new hydrperoxyl rate measurement has resulted in an important change in the effect of NO_x emissions on ozone in the stratosphere.

In the troposphere, the effect of combined injection of NO_2 and H_2O is a production of ozone. This ozone increase is due to the increase in concentration of $O(^3P)$. As pointed out by Widhopf, et al. [1977], in the strict NO_2

injection case, the increase in $O(^3P)$ was initiated by R10 which produced OH which, in turn, oxidized methane which then cycled through the smog chain to produce HO_2. The increase in NO_2 produced $O(^3P)$ through R4. The additional injection of H_2O had a slight effect in reducing the level of ozone increase; this is a result of the formation of HNO_3 in the troposphere which is then rained out, reducing the level of NO_2 and thus $O(^3P)$, i.e.

$$H_2O + O(^1D) \rightarrow OH + OH \qquad R32$$

$$OH + NO_2 + M \rightarrow HNO_3 + M \qquad R12$$

$$NO_2 + h\nu \rightarrow NO + O(^3P) \qquad R4$$

$$O(^3P) + O_2 + M \rightarrow O_3 + M \qquad R5$$

In the stratosphere, injection of H_2O reduces the ozone increase due to NO_x injection by introducing additional OH and HO_2, i.e.

$$H_2O + O(^1D) \rightarrow OH + OH \qquad R32$$

$$O_3 + OH \rightarrow O_2 + HO_2 \qquad R9$$

$$O_3 + HO_2 \rightarrow OH + O_2 + O_2 \qquad R14$$

Thus, the combined effect of the injection of NO_x and HO_x for these calculations is to increase ozone in both the troposphere and stratosphere. Since the mechanisms in both the stratosphere and troposphere are strongly dependent on the rate at which the reaction $HO_2 + NO \rightarrow OH + NO_2$ proceeds, together with the fact that the use of this rate resulted in substantial increases in the ozone levels in the natural atmosphere above observed levels, it was definitely felt that other reaction rates involving the hydroperoxyls were still inaccurate. Possible candidate hydroperoxyl reaction rates that should be investigated further were suggested [Widhopf and Glatt (1978)]. These

recommendations were based on our analysis of the controlling chemical mechanisms in the aforementioned natural and perturbed results. Since we found that in the natural atmosphere the overprediction could not be accounted for by transport modifications alone, we suggest that the following reactions involving the production or depletion of $O(^3P)$, those depleting ozone, and important reactions involving the partitioning of OH, HO_2, and H_2O, should be investigated further.

$$OH + O_3 \rightarrow O_2 + HO_2 \qquad R9$$

$$HO_2 + O_3 \rightarrow OH + O_2 + O_2 \qquad R14$$

$$HO_2 + O(^3P) \rightarrow OH + O_2 \qquad R15$$

$$OH + HO_2 \rightarrow H_2O + O_2 \qquad R16$$

$$O(^1D) + H_2O \rightarrow OH + OH \qquad R32$$

$$OH + O(^3P) \rightarrow O_2 + H \qquad R34$$

$$OH + OH \rightarrow H_2O + O(^3P) \qquad R38$$

$$HO_2 + h\nu \rightarrow OH + O(^3P) \qquad R40$$

8.2 $HO_2 + O_3$ (R14) RATE CHANGE

Subsequently, new direct measurements of the rate at which the reaction R14 ($HO_2 + O_3 \rightarrow OH + 2\,O_2$) proceeds were made by Zahniser and Howard [1978]; this rate was significantly different than previous values obtained from indirect means. With the use of this new reaction rate, the natural atmosphere was recalculated employing the chemistry listed in Table IIb. The results for the ozone column variation are shown in Fig. 11. Here, the calculations are seen to be in much better agreement with observations than the previous result, confirming our conclusion that the previous overprediction of ozone was mostly chemically related. The ozone column is in good

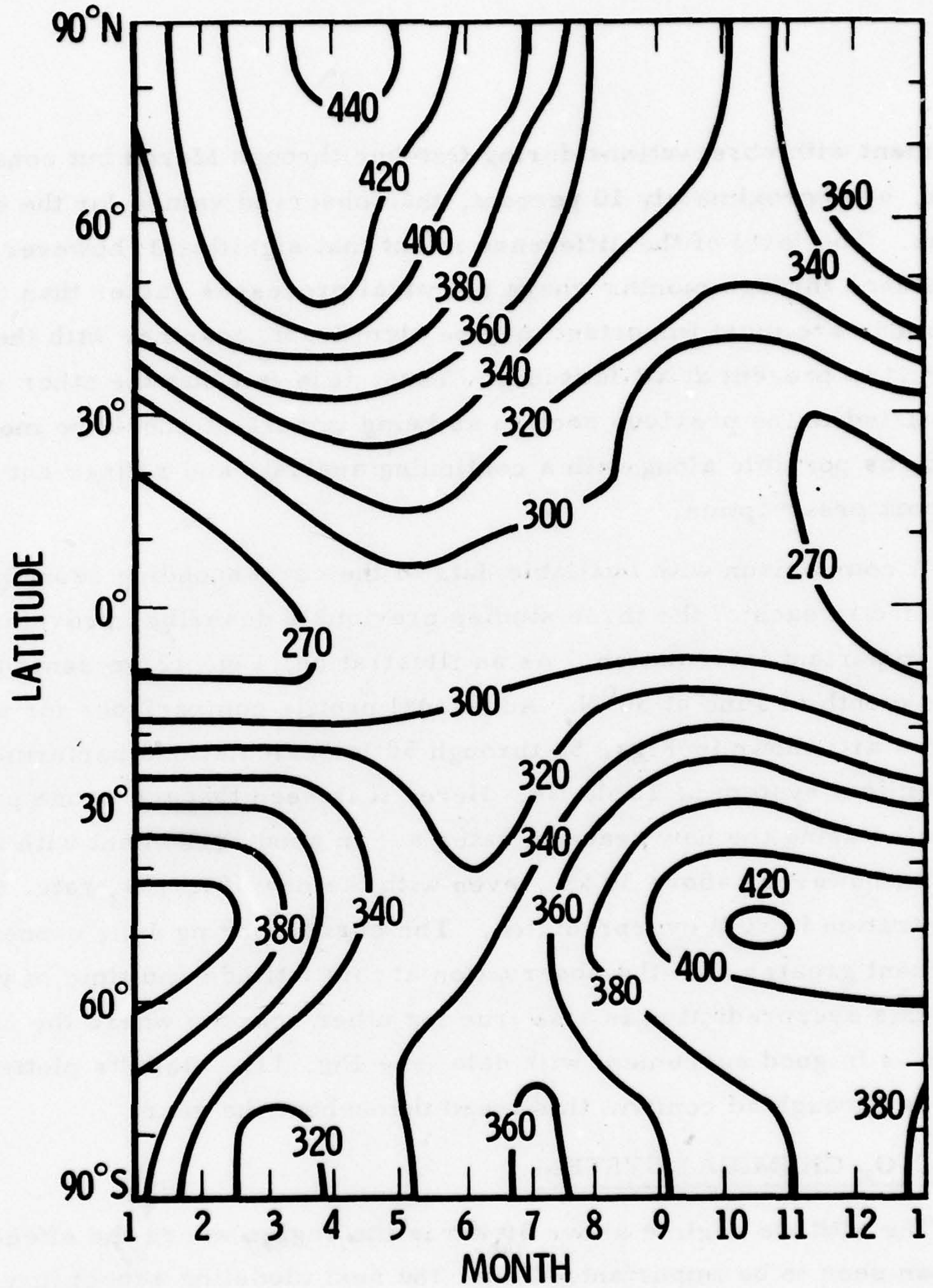

Fig. 11. **Calculated Monthly Variation of the Total Ozone Column as a Function of Latitude (10^{-3} cm at STP) Using the Chemical System in Table IIb**

agreement with observations during October through March but consistently larger, by approximately 10 percent, than observed values for the other months. The level of the difference is not that significant; however, its persistence through months where chemical processes rather than transport phenomena are most important may be significant, together with the fact that the trend is present at all latitudes. Thus, it is felt that the other reaction rates listed in the previous section as being important should be measured as soon as possible along with a continuing analysis and refinement of the transport prescription.

A comparison with available data of the corresponding ozone profiles calculated in each of the three studies previously described provides additional important information. As an illustration, Fig. 12 presents an example for the month of June at 30^{o}N. Additional profile comparisons for selected latitudes are shown in Figs. 5a through 5d for calculations performed using the chemical system of Table IIb. Here, it is seen that the ozone profiles calculated using the new reaction rates are in good agreement with data below ~30 km; however, above 30 km, even with the new $HO_2 + O_3$ rate, the ozone concentration is still overpredicted. The corresponding June ozone column is 10 percent greater than the observation at this latitude and time of year; however, this overprediction is also true for other seasons where the ozone column is in good agreement with data (see Fig. 11). Results plotted in Figs. 5a through 5d confirm this trend throughout the year.

8.3 ClO_x CHEMICAL SYSTEM

The altitude regime above 30 km is the region where the effect of ClO_x has been seen to be important. Thus, the next modeling aspect investigated in this study was the inclusion of ClO_x. Since much of the available ozone data [Dütsch (1971)] have been taken before there were any significant ClO_x source emissions in the atmosphere, coupled with the fact that there is no agreement on how much ClO_x is presently in the atmosphere and what future emissions will be, the effect of ClO_x on ozone was performed parametrically in this study. This allowed for study of the effect of ClO_x on species

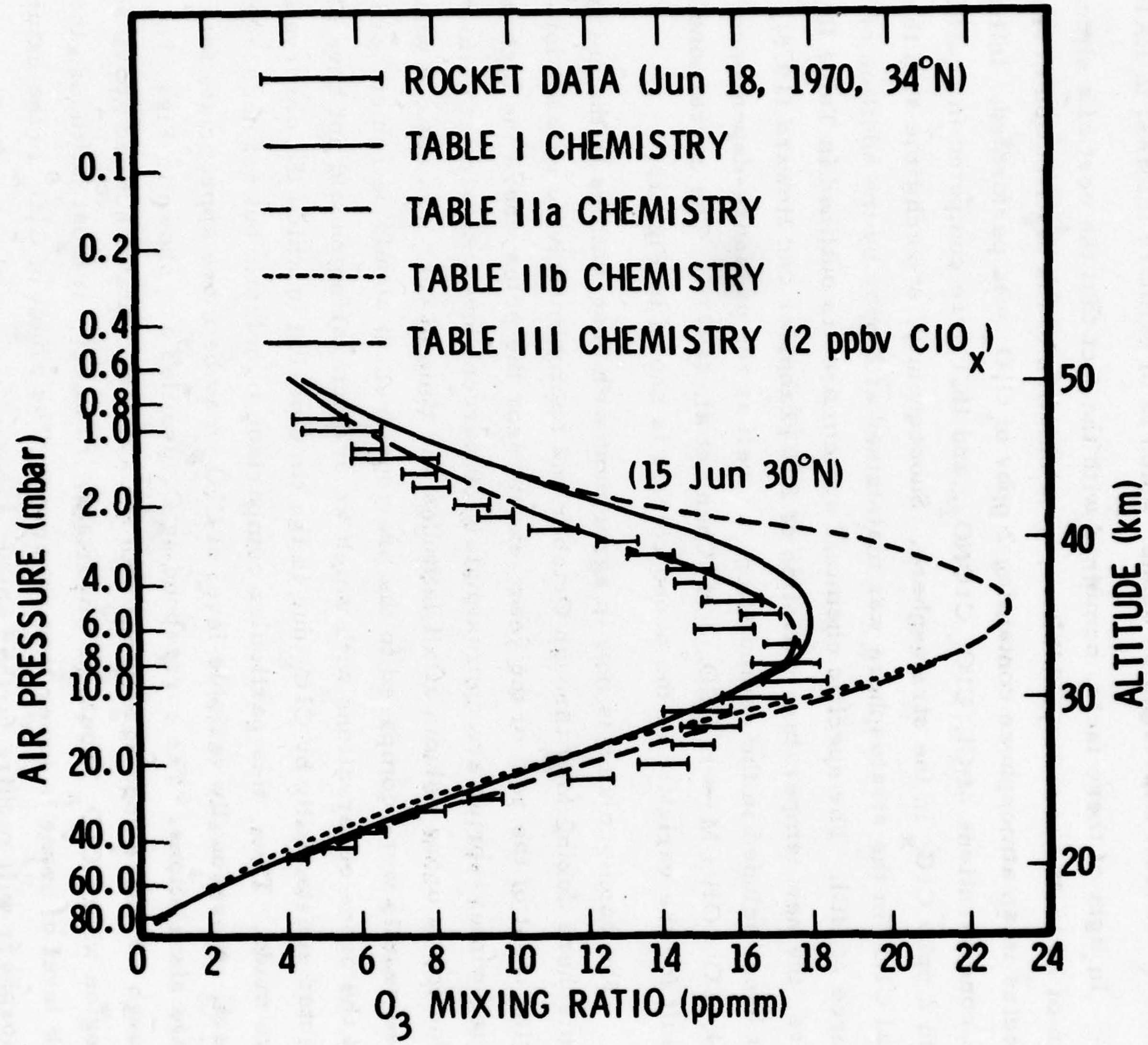

Fig. 12. Comparison of Calculated Ozone Profile (15 June at 30° N) with Measurements

distributions and for preliminary investigation of the effect of combined NO_x and HO_x aircraft emissions on ozone, which is of primary interest to HAPP.

In light of these facts, combined with the fact that the cost of a simulation of 20 to 40 years is prohibitive, a calculation of the distribution of trace species in an atmosphere containing 2 ppbv of ClO_x was performed. Initially, the concentrations of Cl, ClO, $ClONO_2$, and HCl were computed in equilibrium, with 2 ppbv ClO_x in the stratosphere. Subsequently, at each time step the total ClO_x in the stratosphere was maintained at 2 ppbv by the addition of a source of HCl. The specific chemical system used is outlined in Table III. Here, the new temperature variation of R10 [Zahniser and Howard (1978)] has been included in the computation, as well as the pressure-dependence for R44, $CO + OH + M \rightarrow H + CO_2 + M$ [Chan, et al. (1977)]. The corresponding result for the variation of the ozone column is shown in Fig. 13.

The ozone column is now in agreement with observations in the northern hemisphere during May through October and approximately 10 percent lower during most of the rest of the year, except near the poles where the high levels during winter-spring are approximately 20 percent low. An almost uniform reduction in ozone column at all latitudes and time of year was noticed when these results were compared to the previous one. It should be remembered that the ozone observations with which we are comparing should not have been affected substantially by ClO_x due to the time period in which the observations were made. Thus, this particular comparison is helpful, but not necessarily direct. A seasonally variable level of ClO_x may be more appropriate for future simulations. The corresponding O_3 profiles are shown in Figs. 5a through 5d where good agreement with the available data is noticed above 30 km, a region where ClO_x should be important. However, at most latitudes, the peak level of ozone is lower than observed. The effect of ClO_x in the natural atmosphere will require further study, especially since the resultant ozone reduction is more than we anticipated and other levels of ClO_x will need to be studied.

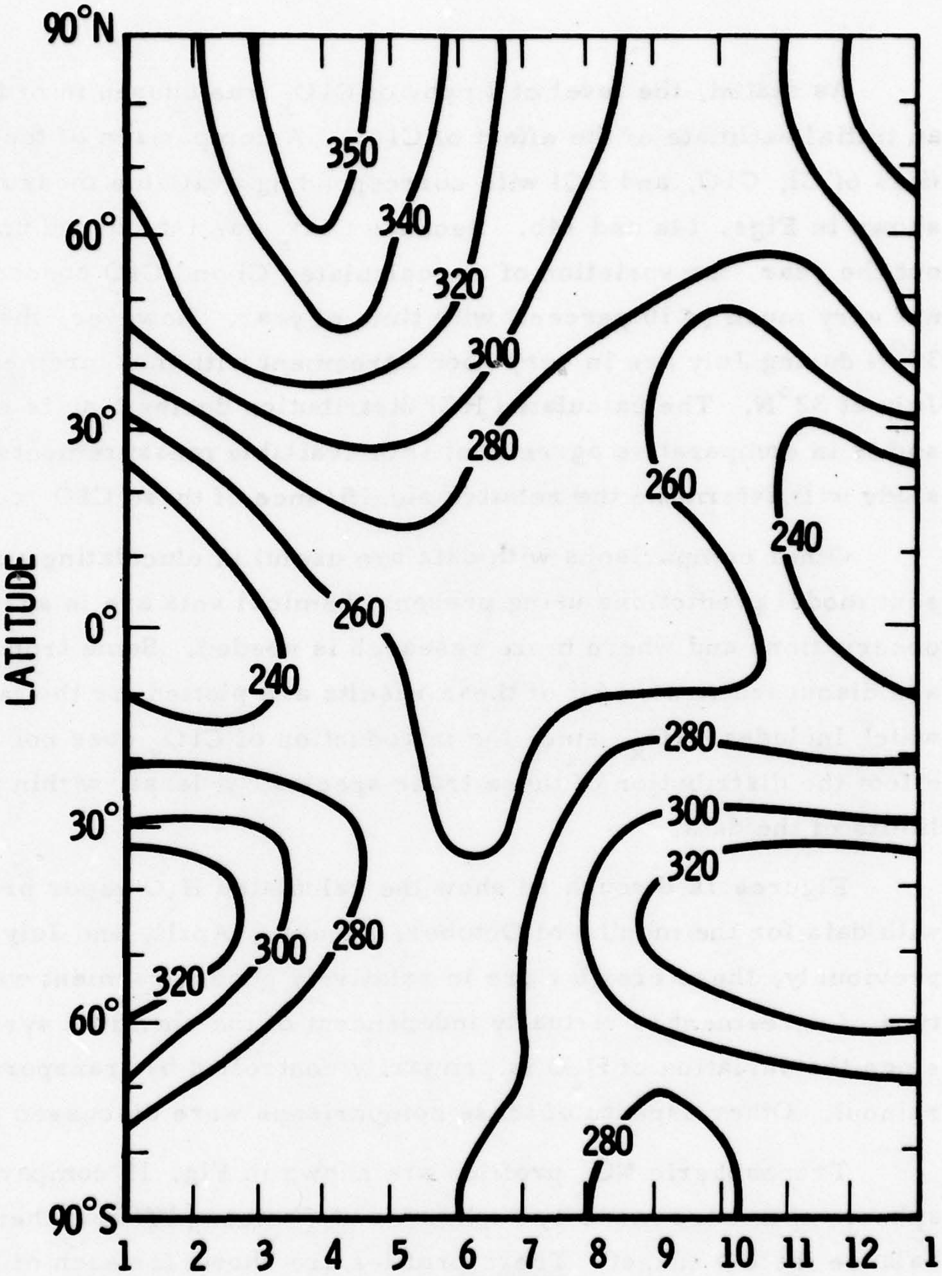

Fig. 13. Calculated Monthly Variation of the Total Ozone Column as a Function of Latitude (10^{-3} cm at STP) Using the Chemical System in Table III (2 ppbv ClO_x)

As stated, the level of 2 ppbv of ClO_x was chosen in order to provide an initial estimate of the effect of ClO_x. A comparison of the calculated profiles of Cl, ClO, and HCl with corresponding available measurements is shown in Figs. 14a and 14b. Because ClO_x was introduced uniformly throughout the year, the variation of the calculated Cl and ClO concentrations does not vary much (<10 percent) with time of year. However, the profiles at 30^{o}N during July are in very good agreement with measurements made during July at 32^{o}N. The calculated HCl distribution during May is shown in Fig. 14b and is in comparative agreement with available measurements. Further study will determine the relative significance of these ClO_x comparisons.

Other comparisons with data are useful in elucidating areas where present model predictions using present chemical sets are in agreement with observations and where more research is needed. Some tropospheric results are discussed first. All of these results are plotted for the last calculation which includes ClO_x, since the introduction of ClO_x does not substantially effect the distribution of these trace species, at least, within the accuracy limits of the data.

Figures 1a through 1d show the calculated H_2O vapor profiles compared with data for the months of October, January, April, and July. As discussed previously, these profiles are in relatively good agreement with data. This type of agreement is virtually independent of the chemical system considered, since the variation of H_2O is primarily controlled by transport processes and rainout. Other aspects of these comparisons were discussed previously.

Tropospheric NO_x profiles are shown in Fig. 15 compared to tropospheric estimates made by Fishman and Crutzen [1978] in their attempt to balance the CO budget. These profiles are shown for each of the sets of reaction rates outlined in Tables I through III. The rapid increase in the concentration of NO_x in the lower few kilometers is due to the inclusion of anthropogenic sources of NO_x at the surface. A dramatic reduction in the NO_x level from that calculated using the 1976 Table I chemical system is obtained with the introduction of the new $NO + HO_2$ rate. Subsequent changes are not very profound for the chemical systems of Tables IIb and III.

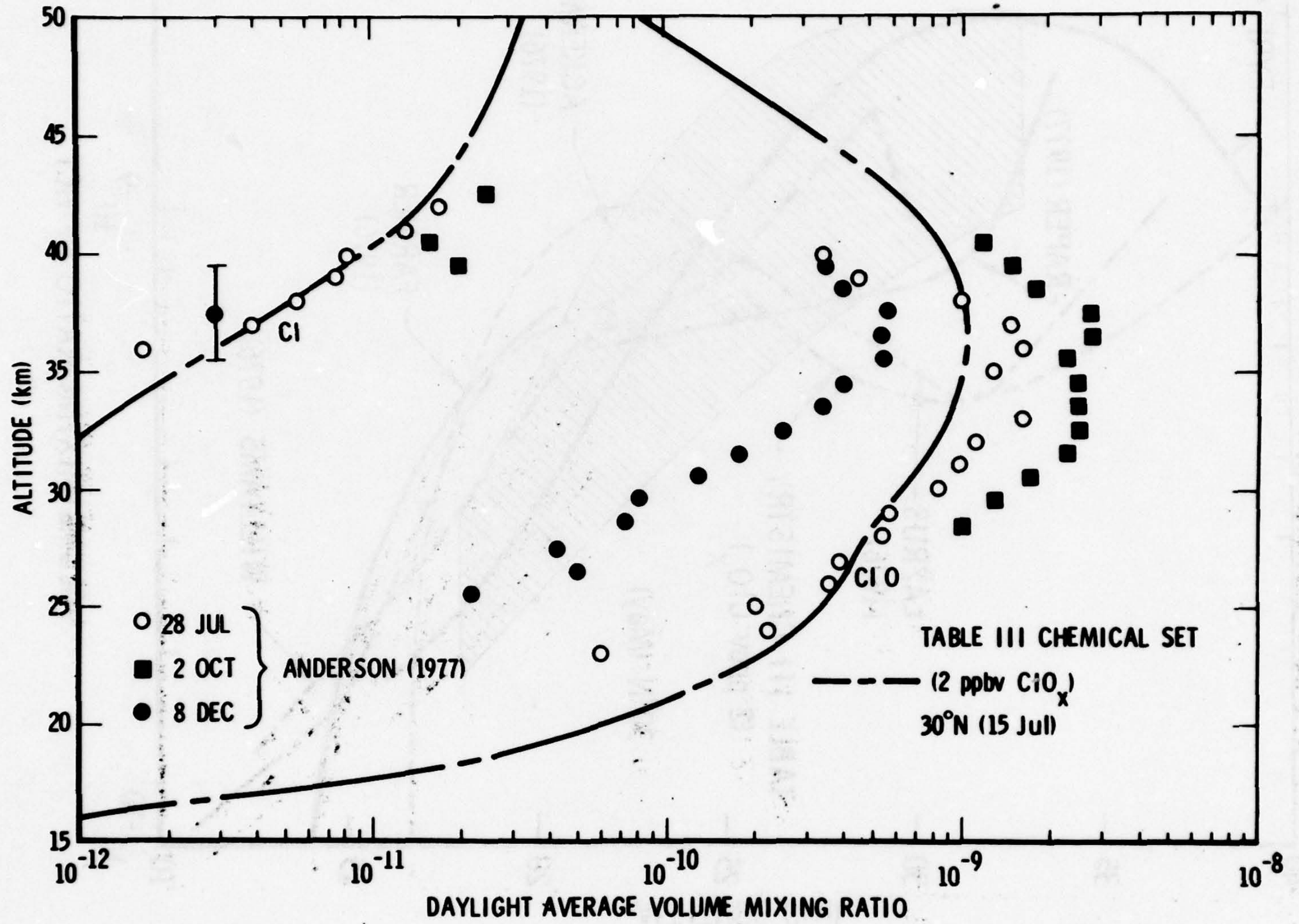

Fig. 14a. Comparison of Calculated and Observed Cl and ClO Profiles

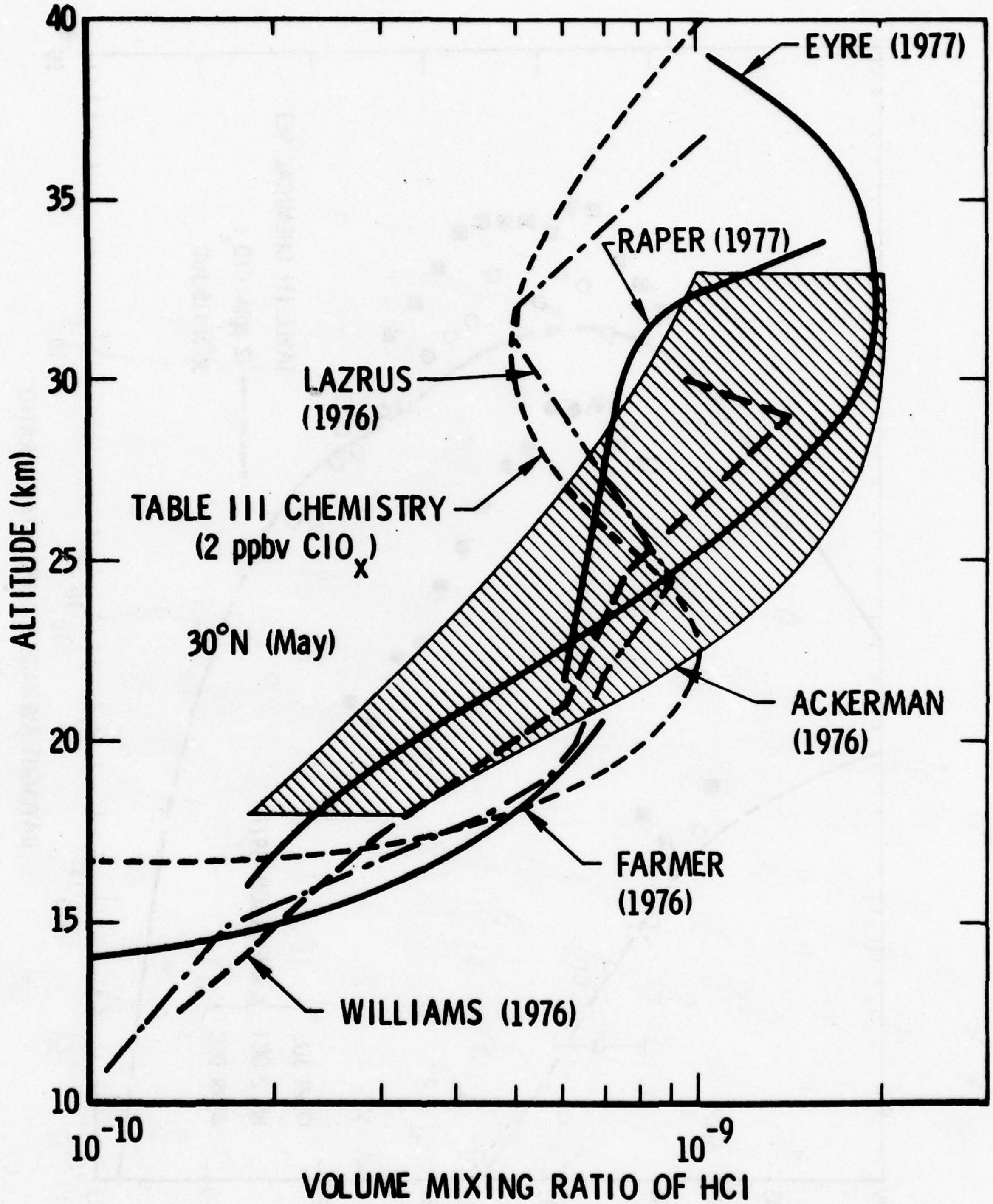

Fig. 14b. Comparison of Calculated and Measured Distribution of HCl

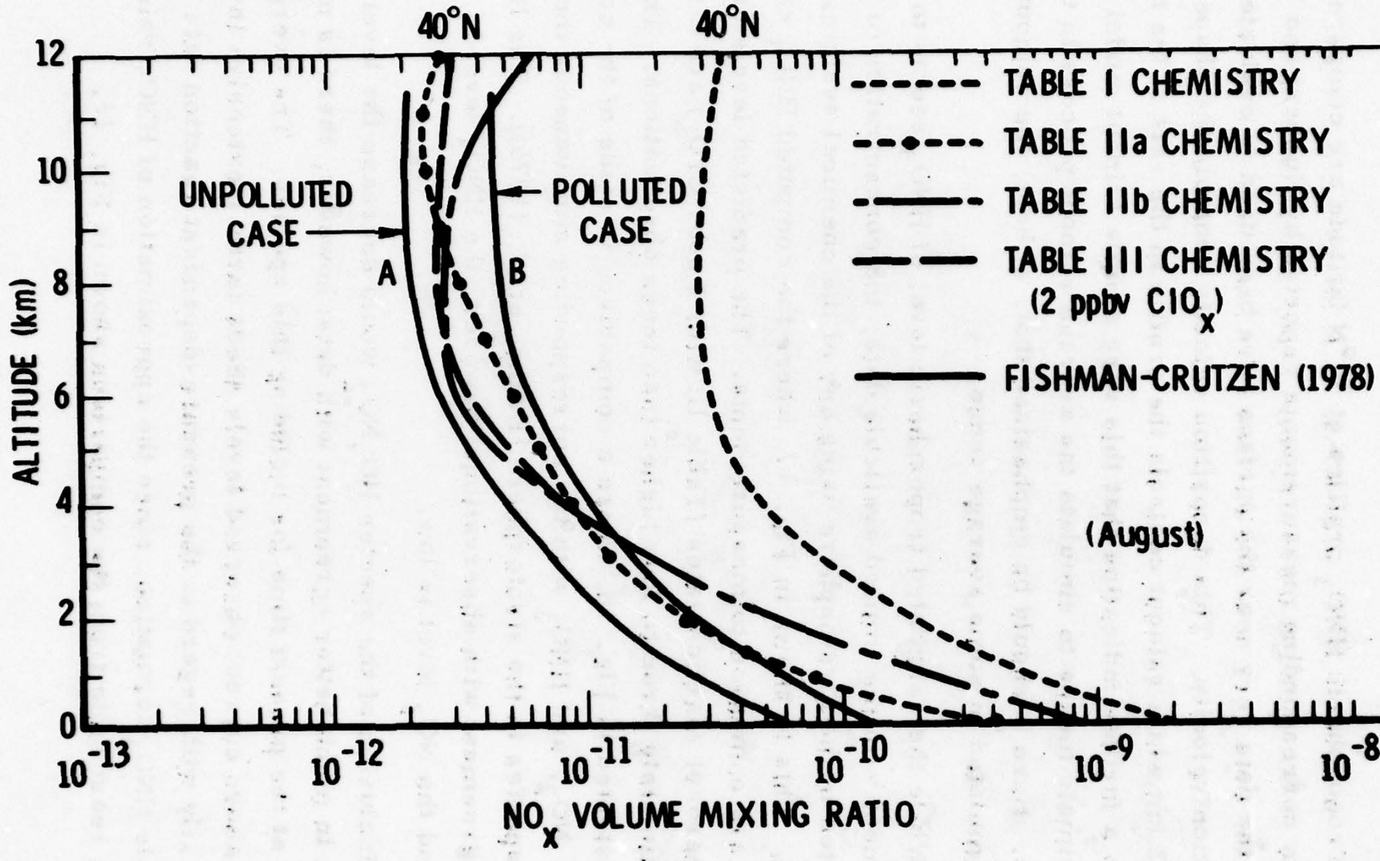

Fig. 15. Comparison of Calculated NO_x Profiles in Troposphere with Fishman-Crutzen Estimated NO_x Profiles

Tropospheric HNO_3 profiles at $30^\circ N$ latitude are compared in Fig. 16, with the corresponding measurements reported by Huebert and Lazarus [1978]. Here, the data very near the surface have been used to evaluate the surface deposition velocity. This deposition velocity controls the shape of the profile below 2 km, while rainout controls the profile in the rest of the troposphere. This is a further indication that this very simple rainout model provides an approximate means to simulate the average rainout process in the troposphere. Here it should be emphasized that, at best, the rainout/washout is only simulated in some average sense.

While the calculated tropospheric level of HNO_3 seems to be in good agreement with the limited available data, the concentration of HNO_3 is overpredicted in the stratosphere using any of the chemical systems in Tables II and III. This is shown in Fig. 17, where the computed HNO_3 columns above 12 km are compared to measurements. The predicted levels using the new hydroperoxyl reaction rates (Table III with 2 ppbv ClO_x) are a factor of approximately three to four higher than these observations. This is also demonstrated in Fig. 18, where a comparison is made of the computed profiles of NO, NO_2, and HNO_3 with the corresponding simultaneous measurements of these species in the stratosphere [Evans, et al. (1976)]. The NO level is in good agreement with observations; however, the HNO_3 level is seen to be too high and the NO_2 level is low.

Inclusion of the species HO_2NO_2 would decrease the level of HNO_3 to values in much better agreement with data; however, there is no solid justification at the present time for including this species. The overprediction of HNO_3 above current observed levels needs further extensive investigation, especially with regard to the pressure-dependent reaction rate (R12) which controls HNO_3 formation, since the approximation of HNO_3 rainout/washout seems reasonable from the comparison shown in Fig. 16.

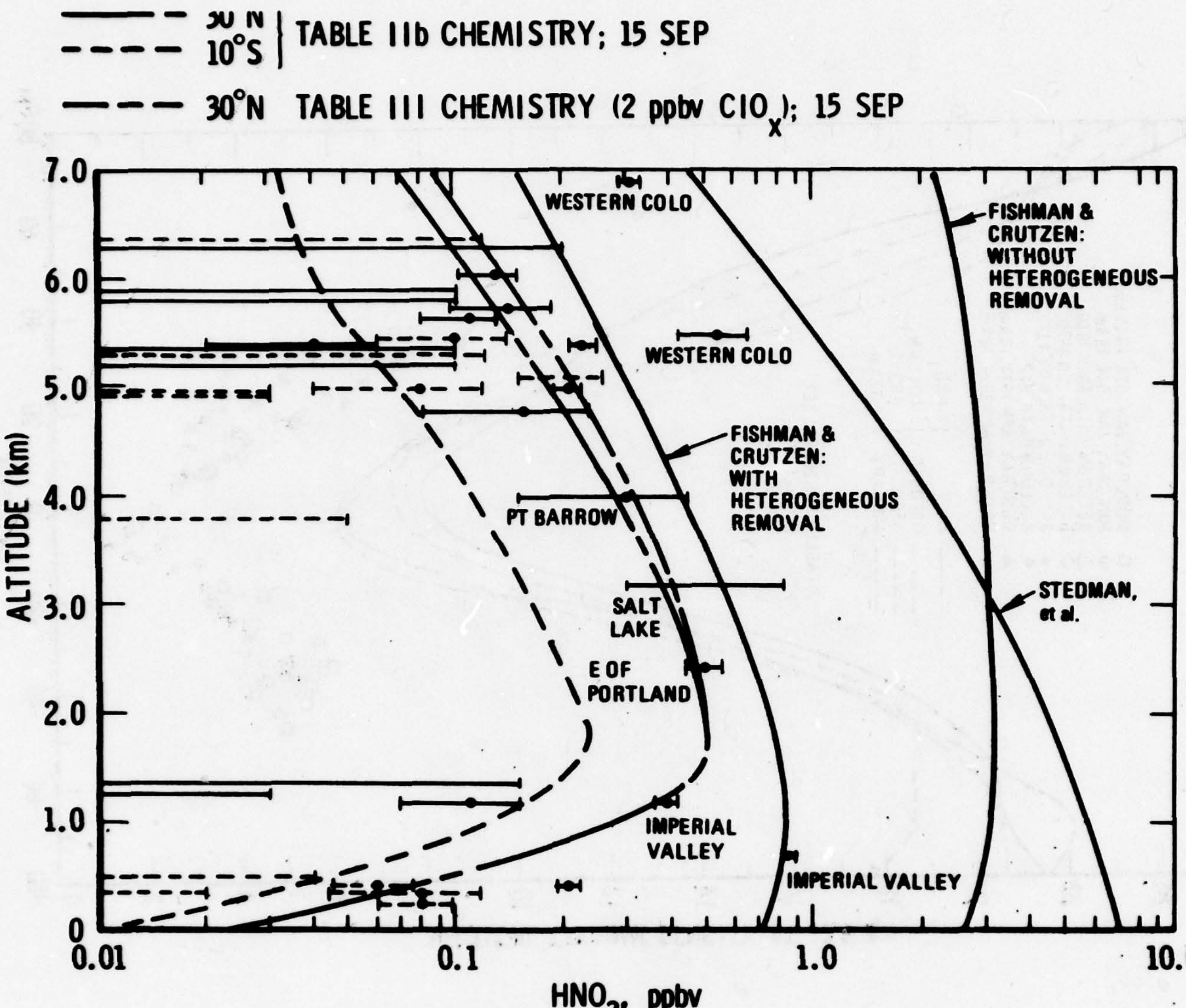

Fig. 16. Predicted and Measured HNO_3 Versus Altitude. Dashed Error-Bars Represent Experimented Marine Values, Solid Bars are Continental Measurements, and Curves are Theoretical Estimates. Locations are Given Primarily for Samples Taken Near Populated Areas. [After Huebert and Lazrus (1978)]

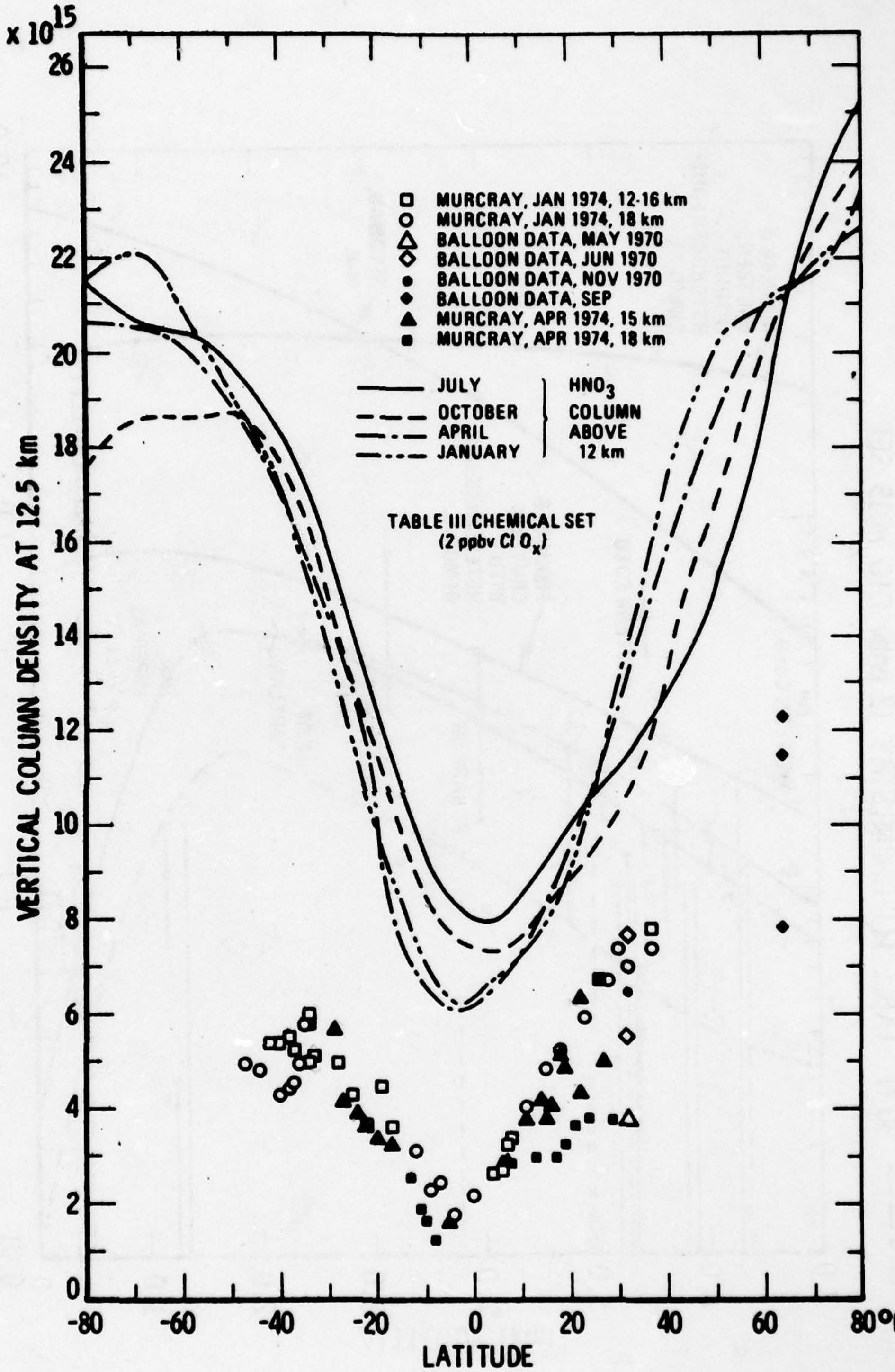

Fig. 17. Comparison of Calculated and Observed HNO_3 Column Variation with Latitude

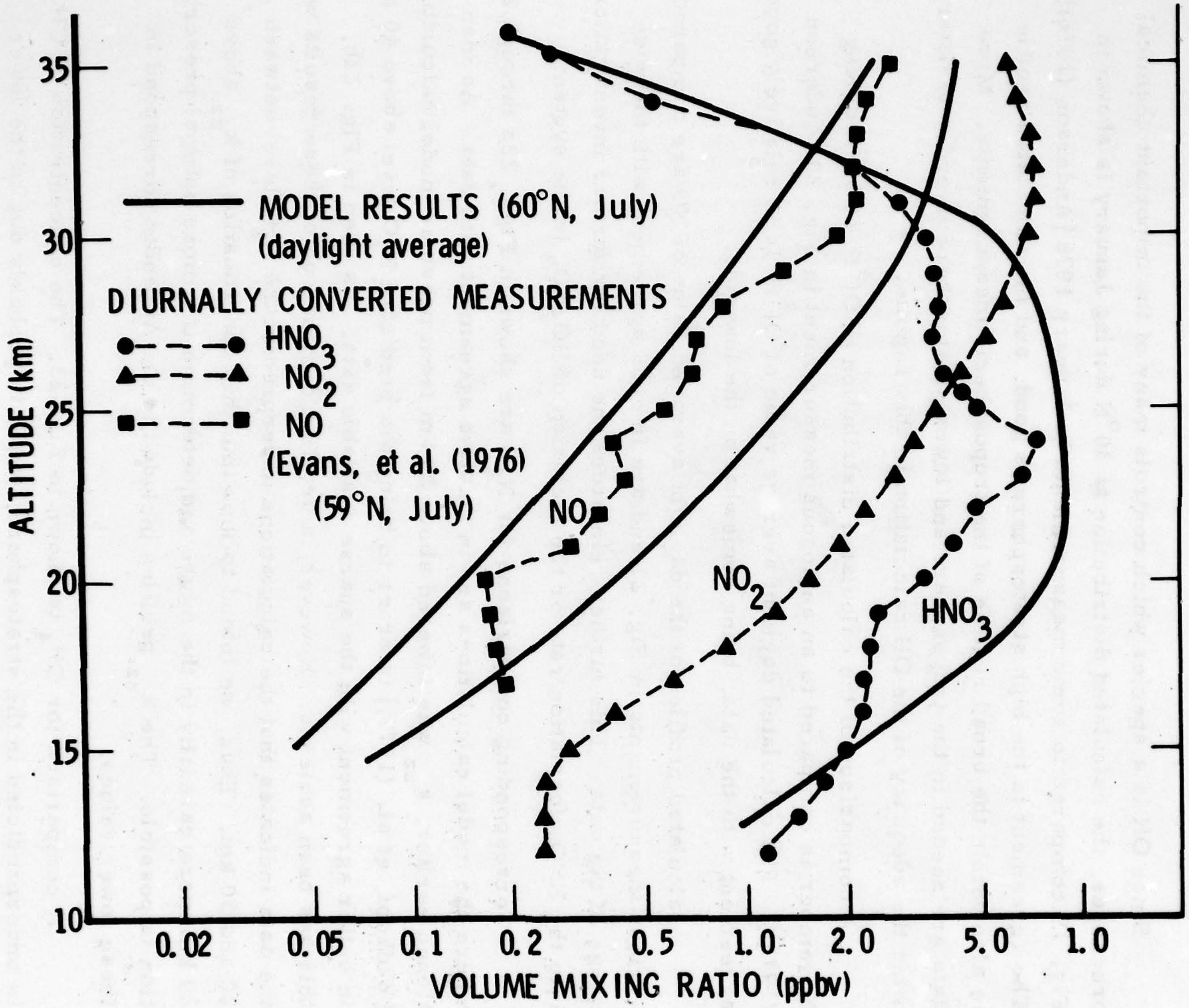

Fig. 18. Comparison of Calculated and Measured Profiles of NO, NO_2 and HNO_3

Since OH is a species which controls many of the important chemical processes, the calculated distribution at 30°N during January is shown in Fig. 19 compared to some measurements in January 1976 [Anderson (1976)]. The agreement in the high stratosphere is good, and the calculated profile is also within the broad regime of the tropospheric measurements. More data are needed in the troposphere and lower stratosphere in order to determine the adequacy of the OH calculation in this regime.

A comparison of the calculated distribution of $O(^3P)$ at 50°N during November is compared to an analogous measurement in Fig. 20 [Anderson (1975)]. The calculated daylight average value of $O(^3P)$ is in relatively good agreement with the data, being somewhat on the low side.

Calculated profiles of the daylight averaged value of NO are compared to various measurements in Fig. 21 and are in good agreement with the wide range of the data. This further reinforces the need for further investigation into the HNO_3 formation rate or the inclusion of HO_2NO_2 in the system.

Corresponding comparisons for N_2O are shown in Figs. 22a through 22c, where the model calculations are in relative agreement with data. As mentioned earlier, k_{zz} was lowered above 20 km from previous model calculations [Widhopf, et al. (1977)] in order to bring the predicted N_2O level above 40 km in better agreement with the sparse available data. As seen in Fig. 22b, this has been achieved. However, a detailed comparison of these results with the data indicates that the calculations underpredict the N_2O level between 20 and 30 km. Thus, we intend to look into this specification of k_{zz} above 20 km more carefully in the future and determine if a more optimal prescription is possible. The k_{zz} profiles included in the Appendix correspond to these lower values.

A comparison for CH_4 is shown in Fig. 23. The concentration of CH_4 is underpredicted in the stratosphere, which is probably due to the lower boundary condition which was set at 1.35 ppmv after the measurements of Ehhalt, et al. [1975]. More recent measurements indicate a level of 1.61 ppmv in the troposphere, which should increase the level of CH_4 in the stratosphere.

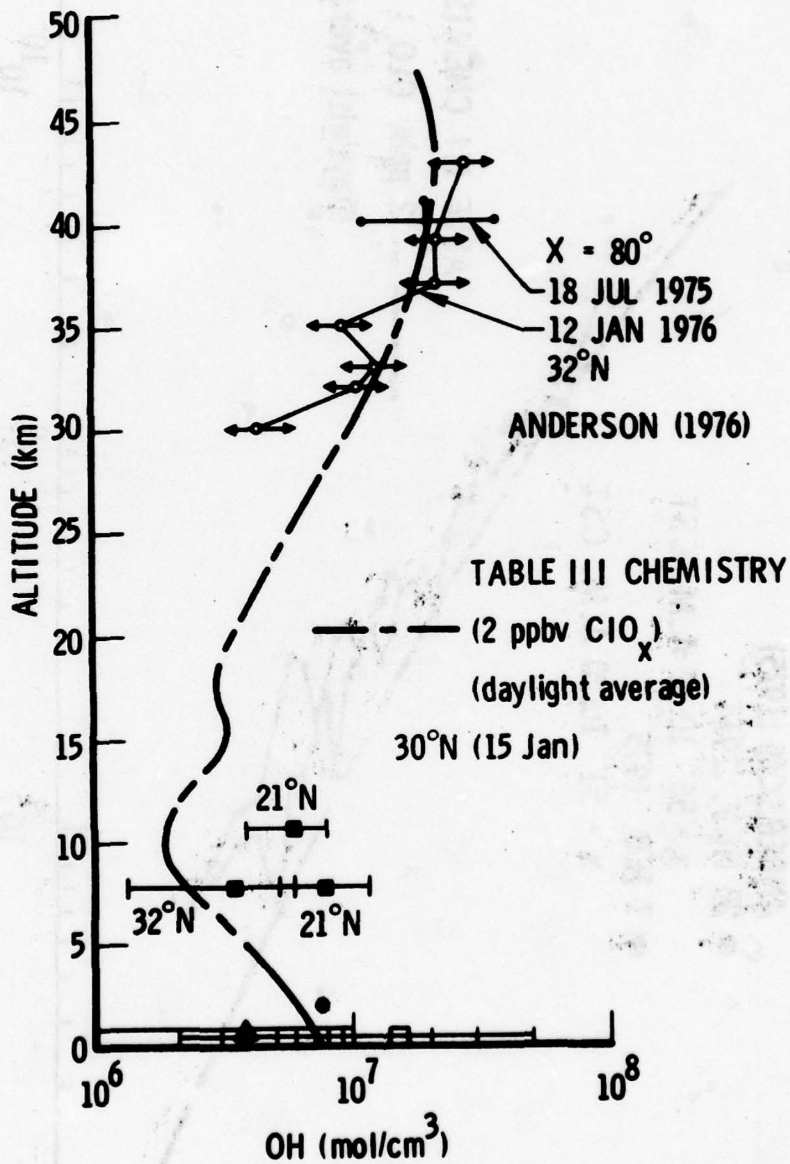

Fig. 19. Comparison of Calculated and Observed OH Concentration

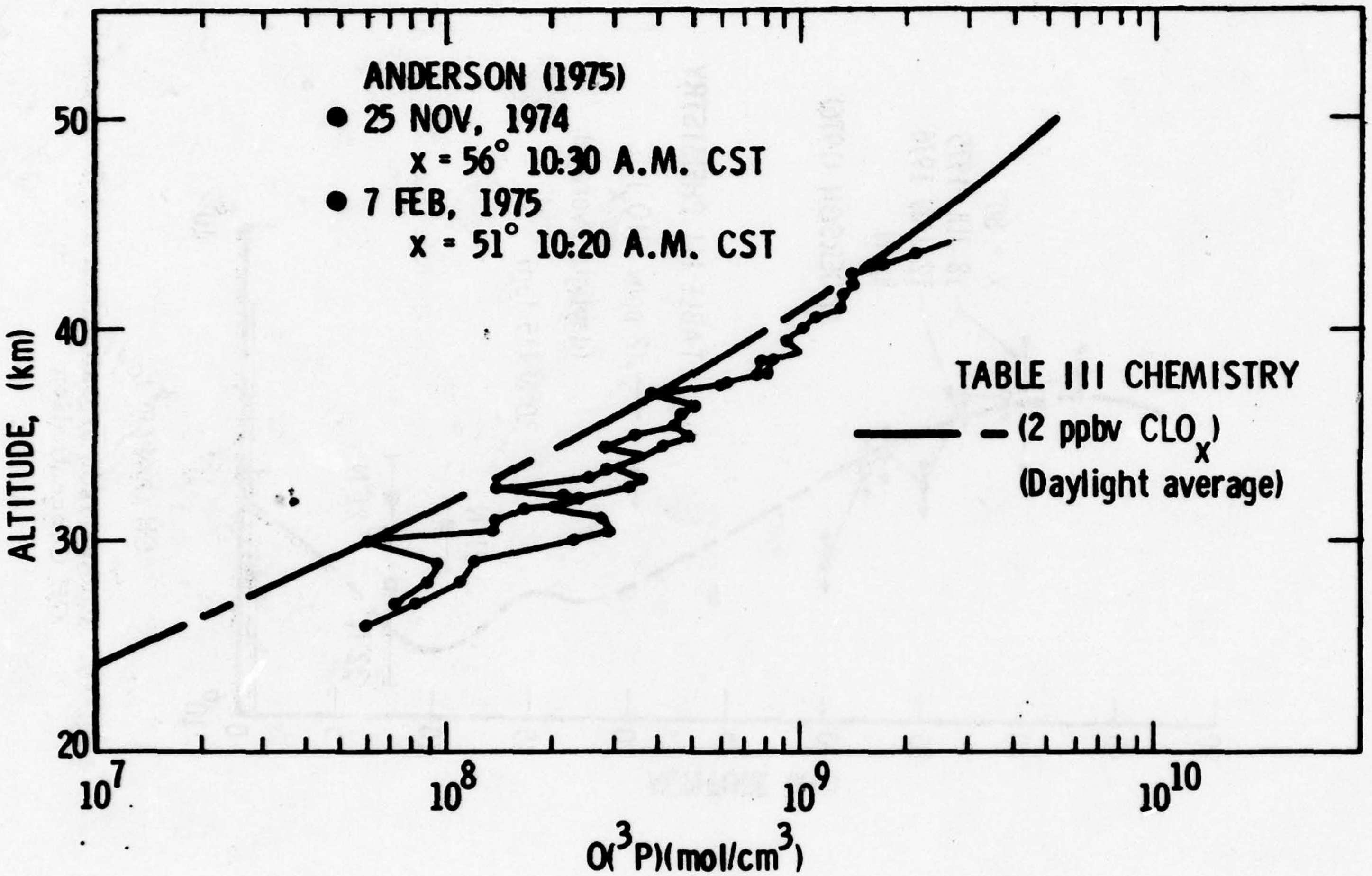

Fig. 20. Comparison of Calculated and Observed Concentration of O(^{3}P)

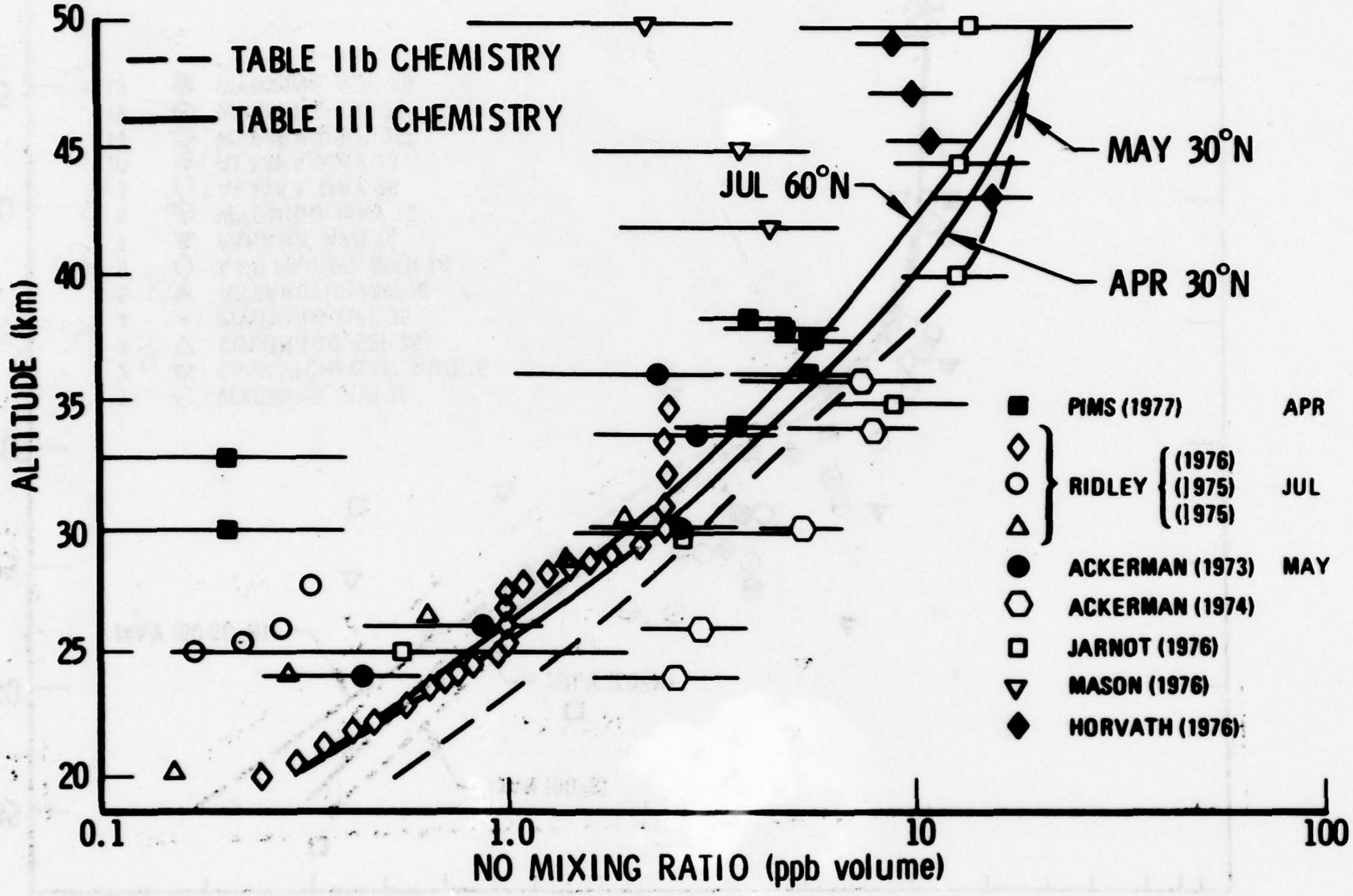

Fig. 21. Comparison of Calculated and Measured Profiles of NO

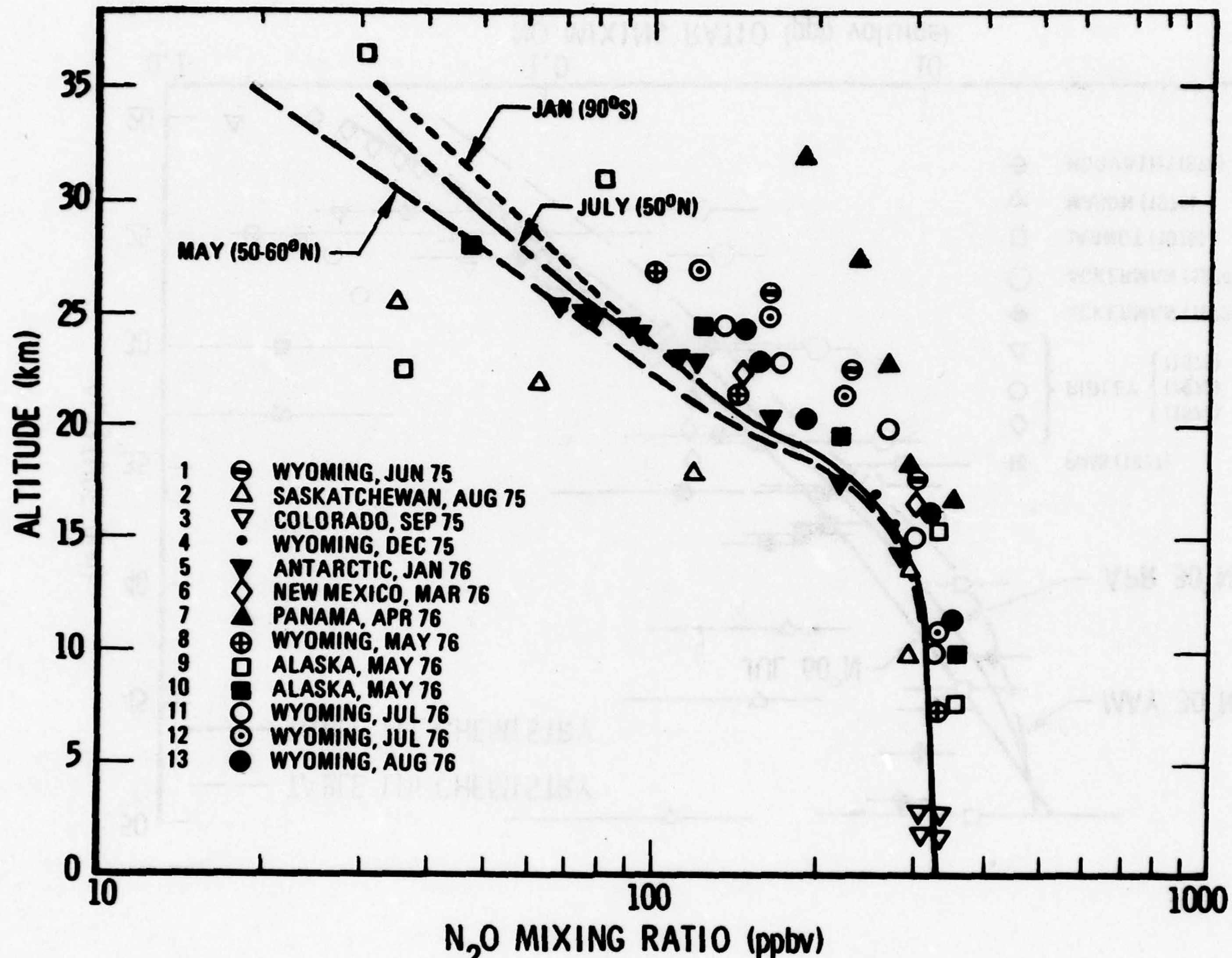

Fig. 22a. Comparison of Calculated N_2O Profiles with Measurements of Schmeltekopf et al (1977)[2]

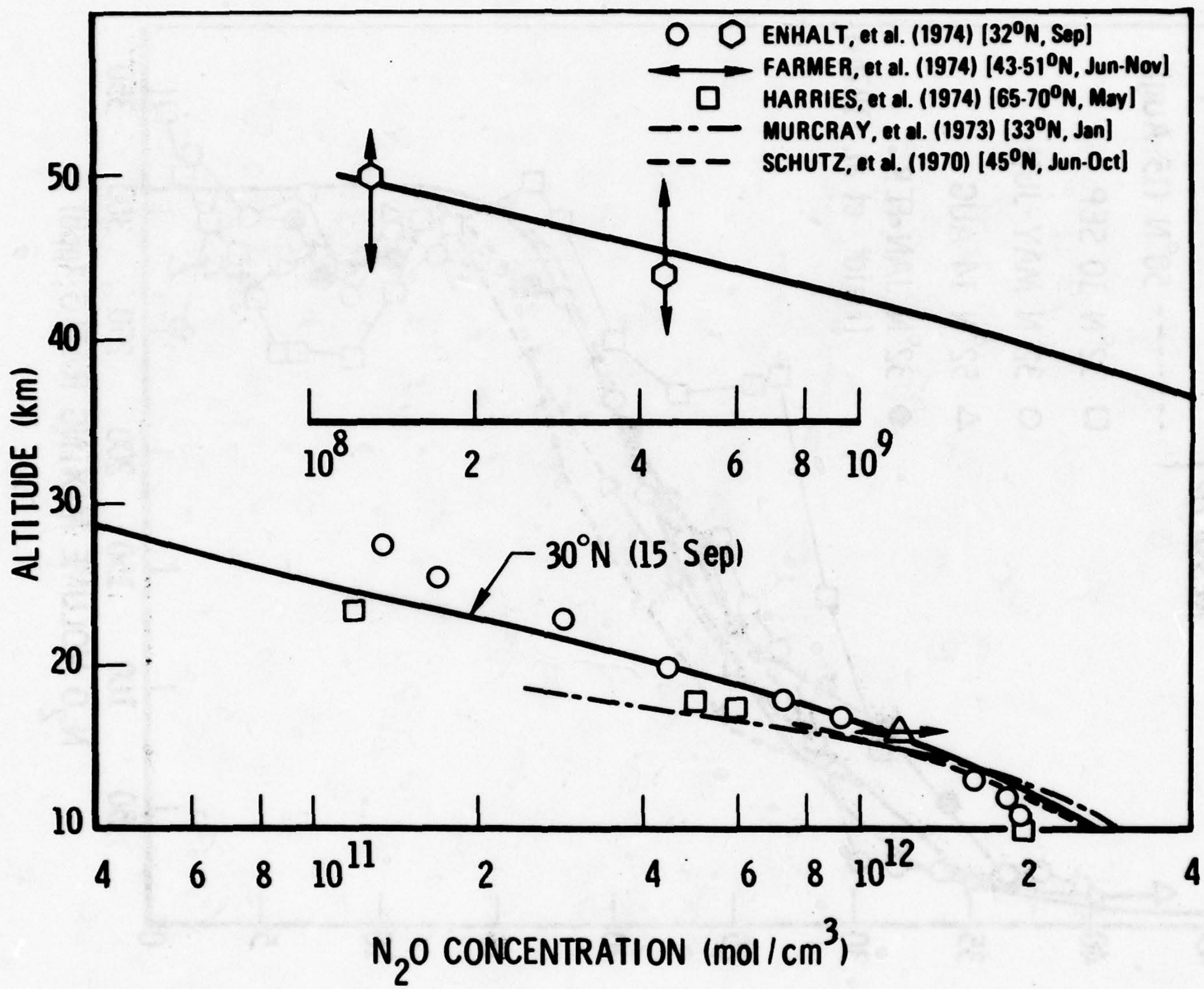

Fig. 22b. Comparison of Calculated N_2O Profiles with Measurements

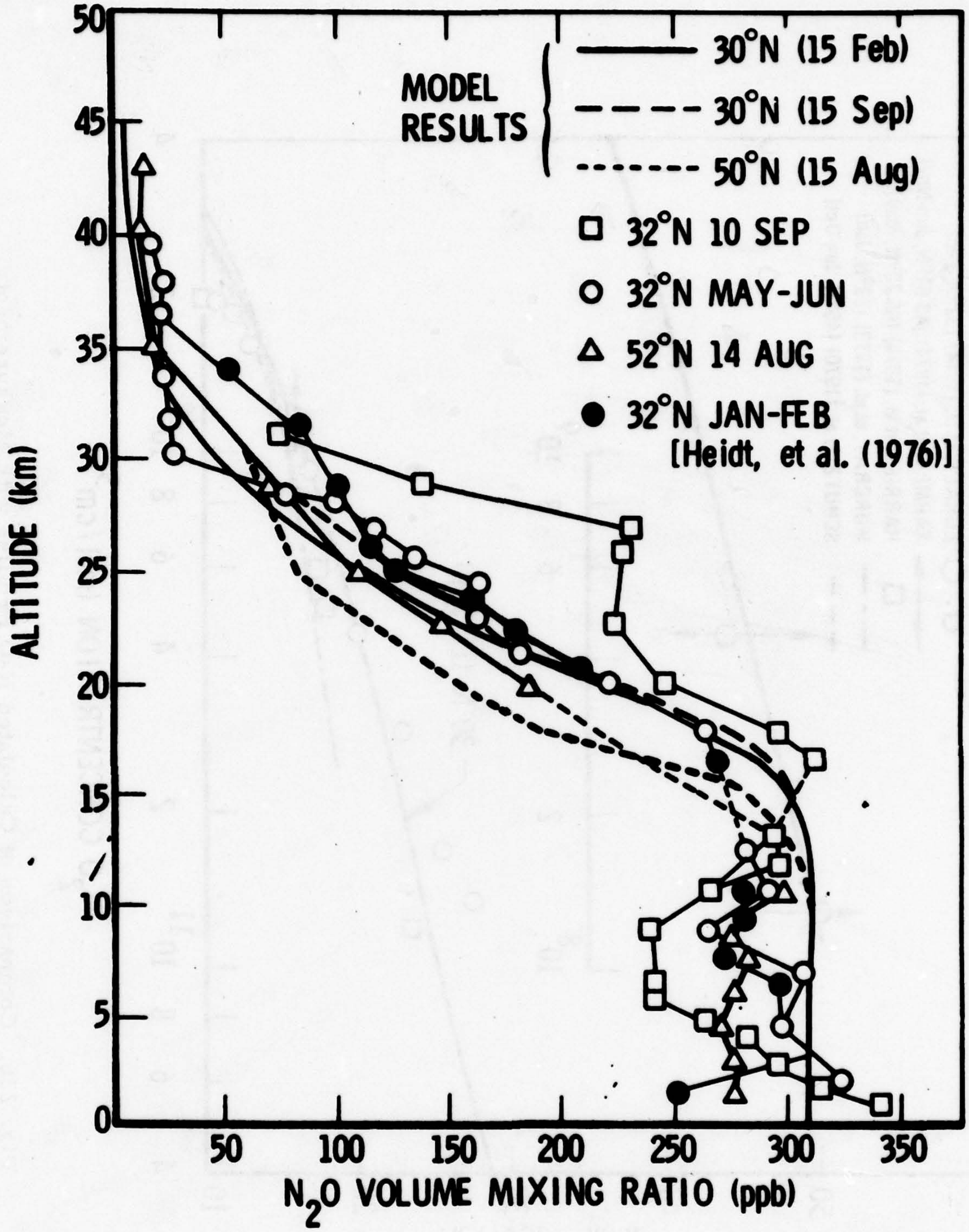

Fig. 22c. Comparison of Calculated N_2O Profiles with Measurements of Schmeltekopf et al

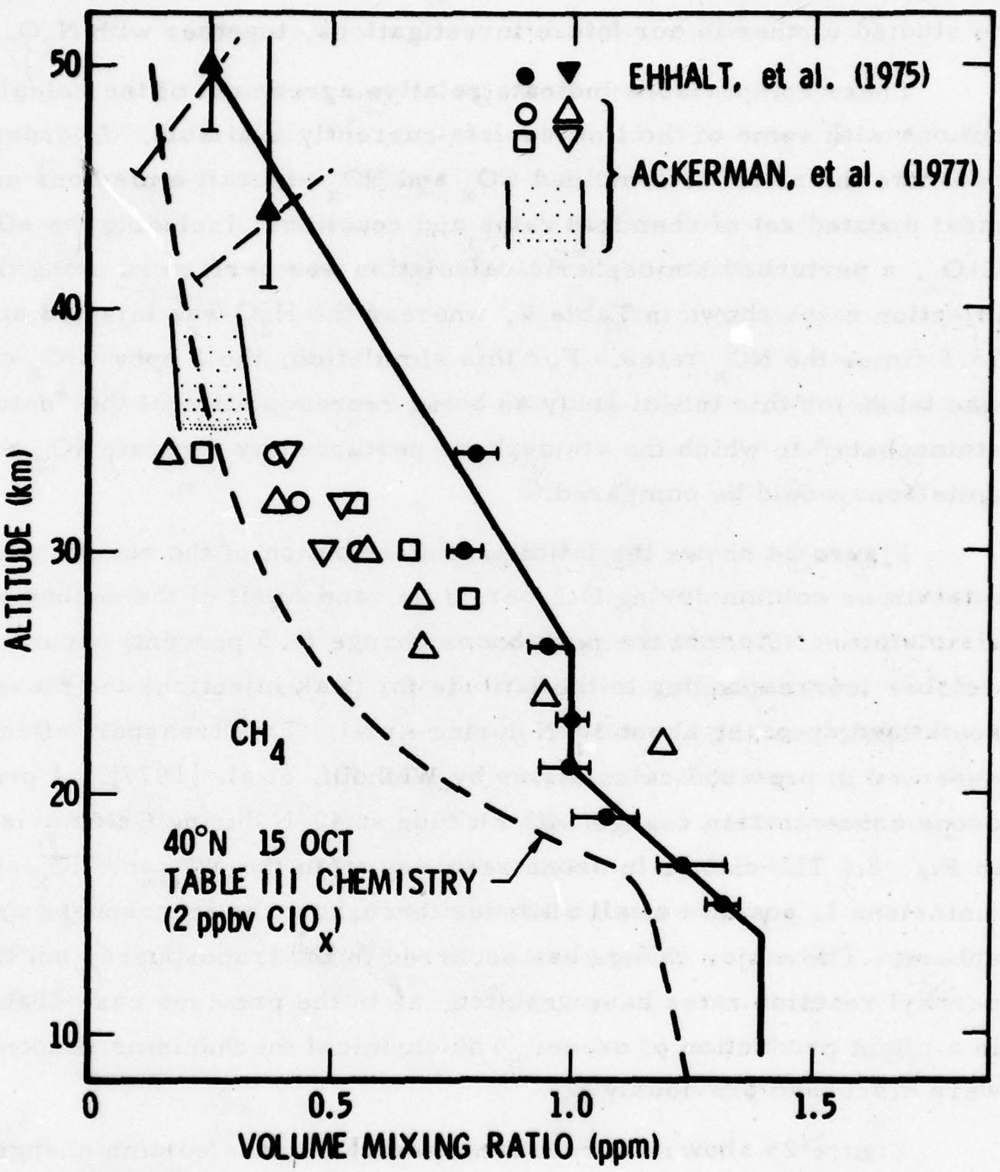

Fig. 23. Comparison of Calculated and Measured CH_4 Profile

Since the CH_4 distribution is dependent upon chemical processes as well as transport, the resolution of this disagreement is not straightforward and will be studied further in our future investigations, together with N_2O.

These comparisons indicate relative agreement of the calculated distributions with some of the limited data currently available. In order to estimate the effect of combined NO_x and HO_x aircraft emissions using the most updated set of chemical rates and reactions, including the effect of ClO_x, a perturbed atmospheric calculation was performed using the NO_x injection rates shown in Table V, whereas the H_2O was injected at a rate 73.5 times the NO_x rates. For this simulation, the 2 ppbv ClO_x calculation was taken for this initial study as being representative of the "natural atmosphere" to which the atmosphere perturbed by aircraft NO_x and H_2O emissions would be compared.

Figure 24 shows the latitudinal distribution of the resultant change in total ozone column during October, July, and April of the second year of simulation. Note that the peak ozone change (3.5 percent) occurs at 40°N in October (corresponding to the latitude for peak injection) and moves slightly southward, peaking about 30°N during April. This transport effect has been observed in previous calculations by Widhopf, et al. [1977]. A profile of the ozone concentration change with altitude at 40°N during October is included in Fig. 8. The change in ozone resulting from the NO_x and HO_x aircraft emissions is positive at all altitudes throughout the troposphere and stratosphere. The major change has occurred in the troposphere, but the new hydroperoxyl reaction rates have resulted, as in the previous case (Tables IIa, IIb), in a slight production of ozone. The chemical mechanisms responsible for this were discussed previously.

Figure 25 shows the resultant temporal ozone column change at 40°N latitude for the two years of simulation. Also shown is the result of Widhopf and Glatt [1978] for the NO_x and HO_x injection case using the chemical reaction rate data from Table IIa. Note that the peak ozone maxima and minima are approximately equal for both chemical sets IIa and III and occur within a

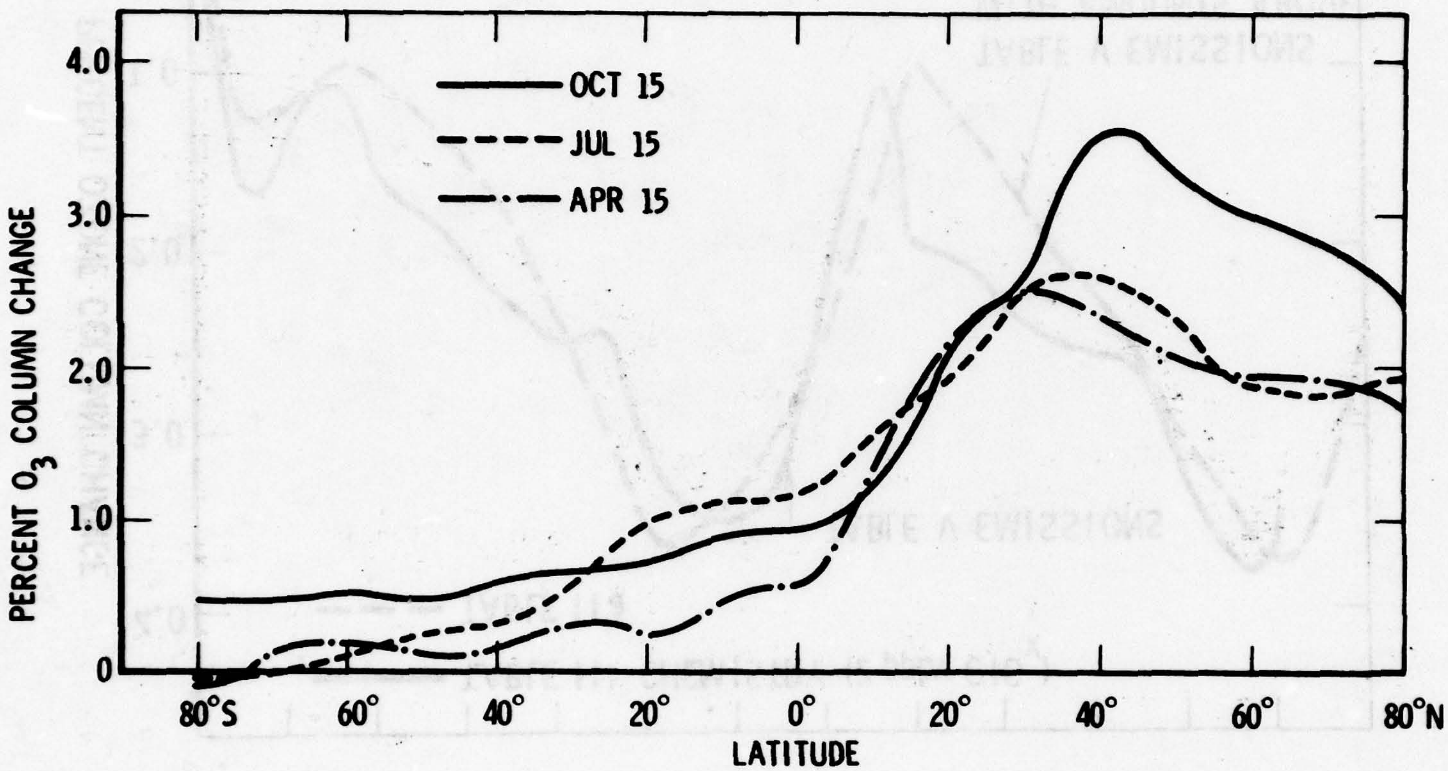

Fig. 24. O_3 Column Change Resulting from NO_x and HO_x Emissions from a Combined Fleet of Subsonic and Supersonic Aircraft (Table IV) Using Chemical Set of Table III (2 ppbv ClO_x)

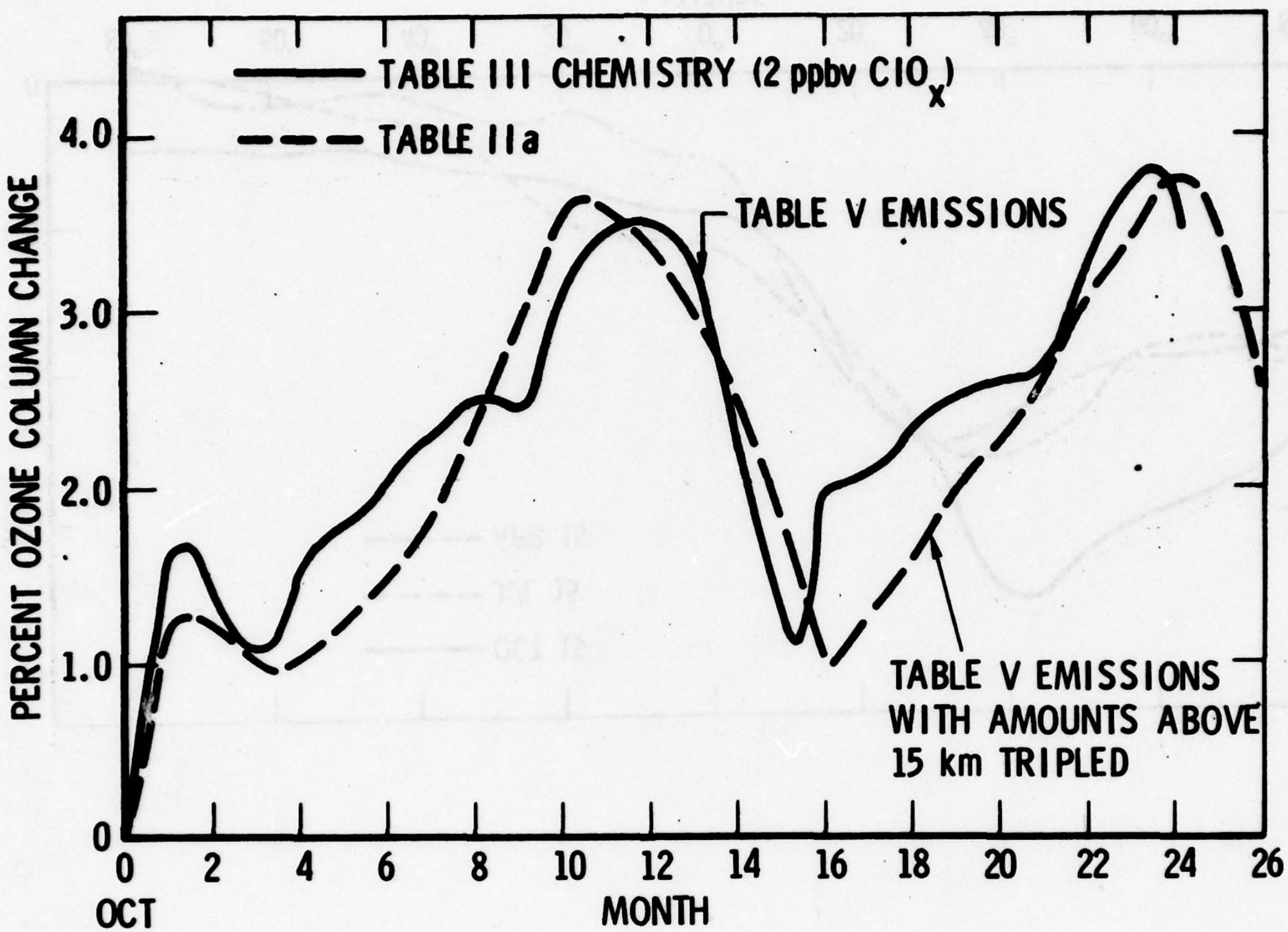

Fig. 25. O_3 Column Change as a Function of Time

month of each other. This result may seem inconsistent, since nearly three times as much injection occurred above 15 km in Widhopf and Glatt [1978] and, in addition, Table III introduces ClO_x which ties up NO_x, i.e.

$$ClO + NO_2 + N_2 \rightarrow ClONO_2 + N_2 \qquad R76$$

Thus, one might expect a lower peak increase in ozone column. This result is found to be true in the stratosphere; however, there is an additional increase of O_3 in the troposphere due to the introduction of the pressure-dependent reaction rate for $CO + OH \rightarrow H + CO_2$. This increase in H produces more HO_2 through the reaction

$$H + O_2 + M \rightarrow HO_2 + M \qquad R35$$

which, in turn, produces more O_3. Thus, for this calculation, it appears the two effects tend to cancel each other out.

The basic mechanisms for ozone increase in both stratosphere and troposphere have been discussed earlier, except the inclusion of the reaction

$$ClO + NO_2 + N_2 \rightarrow ClONO_2 + N_2$$

in the stratosphere when ClO_x is considered. This reaction slightly attenuates the ozone increase in the stratosphere.

One important area of consideration is the determination of what part of the ozone change is due to H_2O injection and what part is due to the NO_x injection. To answer this question, a calculation was performed for a two-year period wherein just NO_x was injected. Table VI shows the resultant percent changes in O_3, $O(^3P)$, NO, NO_2, HNO_3, OH, and HO_2 for various altitudes at 40°N latitude during October for both injection cases. Note that the maximum ozone percent increase occurs at 10 km where the peak injection occurs. For these injection rates, the water has only a slight attenuating

TABLE VI. PERCENT CHANGE IN SPECIES CONCENTRATION DURING 15 OCTOBER FOR NO_x AND HO_x INJECTION CASE (second column) AND NO_x ONLY CASE (first column)

Alt (KM)	O_3		$O(^3P)$		NO		NO_2		HNO_3		OH		HO_2	
4	4.5	- 1.1	4.3	- 1.5	49.2	9.8	3.6	4.1	- 2.6	16.1	70.1	4.9	200.0	76.8
6	27.9	29.3	28.1	28.7	91.2	27.2	54.2	45.0	50.0	5.0	52.0	- 2.3	64.3	44.8
8	84.4	74.7	84.6	74.6	185.1	174.3	210.0	191.0	175.2	105.0	86.7	72.7	121.4	112.3
10	145.2	141.7	147.9	143.1	759.6	725.8	769.0	744.2	368.4	322.8	109.9	99.7	143.5	141.5
12	93.0	91.4	93.2	90.8	310.7	306.4	314.9	311.2	156.5	147.9	57.9	55.2	66.8	63.7
14	22.2	22.1	22.4	21.7	36.9	36.2	47.6	47.2	46.2	45.4	15.1	14.5	- 6.4	- 6.1
16	7.3	7.2	7.6	6.8	16.9	16.6	20.2	19.9	18.6	18.3	0.2	0.2	- 8.8	- 8.1
18	3.3	3.2	3.8	2.9	13.4	12.9	14.0	13.5	10.2	10.0	- 2.8	- 2.6	- 10.8	- 9.2
20	1.4	1.3	2.1	1.1	6.3	6.0	6.0	5.7	4.7	4.6	1.3	0.5	- 2.8	- 2.4
25	0.1	0.1	0.7	- 0.2	1.2	1.2	1.1	1.1	0.5	0.4	1.7	1.6	0.7	1.51
30	.09	.02	0.6	0.2	0.6	0.7	0.7	0.6	- 0.4	- 0.4	2.0	0.4	1.2	0.3

effect on the ozone increase. In the troposphere, the injection of H_2O produces OH through the reaction

$$H_2O + O(^1D) \rightarrow OH + OH \qquad R2$$

which then reacts with NO_2 to form nitric acid through

$$OH + NO_2 + M \rightarrow HNO_3 + M \qquad R12$$

which is then rained out. This loss in NO_2 reduces the increase in $O(^3P)$; thus the ozone increase is slightly lower. In the stratosphere, the increase in OH and HO_2 due to the injection of H_2O lowers the ozone increase due to NO_x injection, through the reactions

$$OH + O_3 \rightarrow O_2 + HO_2 \qquad R10$$

$$HO_2 + O_3 \rightarrow OH + O_2 + O_2 \qquad R14$$

It must be pointed out that the chemical mechanisms described above for controlling the ozone changes correspond to a given set of rate constants and injection rates for NO_x and H_2O, and modification of these rates may lead to other important chemical mechanisms. Future studies are desirable which will vary the level of ClO_x to determine the effect on the stratospheric ozone perturbations. Also, in all of these studies the projected emissions from supersonic aircraft flying in the stratosphere are very small compared to the emissions from subsonic aircraft flying in the troposphere. Thus, the effects in the stratosphere are small compared to those occurring in the troposphere. Therefore, different emission scenarios might weight the results differently and make different mechanisms more important.

Also, the uncertainty regarding the specification of transport and rainout/washout must be kept in mind, since the prescription of these important phenomena are still in an elementary stage because of a combination of an incomplete data base,understanding and an inability of economically calculating them from first principles.

9. CONCLUSIONS

The higher hydroperoxyl reaction rates recently measured have significantly influenced the predicted distribution of trace species and increased the relative importance of HO_x on the atmospheric chemical balance. Current calculated ozone levels are in reasonable agreement with data when calculated using the most recent reaction rates; however, a number of additional important reaction rates need to be measured and are outlined in the text. The distribution of most other species in the troposphere and stratosphere are in relatively good agreement with data; however, stratospheric levels of HNO_3 are significantly overpredicted using current chemical systems and reaction rates. A very simple active water vapor model has been included which seems to adequately predict, within the confines of parameterized models, the natural seasonal tropospheric and stratospheric distribution of water vapor. This has been used to estimate the effect of combined NO_x and HO_x aircraft emissions on ozone, including 2 ppbv of ClO_x in the stratosphere. Ozone is seen to increase in both the stratosphere and troposphere as a result of these emissions, where the total ozone column peaks at approximately 3.5 percent during summer-fall. The new higher hydroperoxyl rates play an important role in determining this level. The major effect is in the troposphere due to the much larger estimated subsonic fleet. As a result, the H_2O emissions play a minor role in the ozone change, since they are a small fraction of the tropospheric water level, whereas the stratospheric emission levels are small due to the small projected fleet of supersonic aircraft.

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APPENDIX

HYDRODYNAMIC AND TRANSPORT PARAMETERS

Listed in this Appendix are the meridional distributions of T, k_{zz}, $k_{\phi z}$, $k_{\phi\phi}$, v and ω for 15 October, 15 January, 15 April, and 15 July as used in the last set of calculations (corresponding to the chemical set in Table III) described in this report.

T (IN UNITS OF 100. DEGREES KELVIN) FOR OCTOBER

			SOUTH					LATITUDE (DEGREES)					NORTH			
ALT(KM)	80	70	60	50	40	30	20	10	0	10	20	30	40	50	60	70	80
50.0	2.785	2.735	2.691	2.674	2.673	2.680	2.691	2.705	2.718	2.728	2.723	2.708	2.678	2.643	2.618	2.598	2.588
47.5	2.799	2.755	2.706	2.683	2.679	2.677	2.677	2.687	2.703	2.703	2.694	2.678	2.653	2.611	2.578	2.553	2.547
45.0	2.754	2.721	2.674	2.644	2.636	2.638	2.643	2.653	2.665	2.663	2.652	2.637	2.609	2.563	2.524	2.499	2.496
42.5	2.685	2.657	2.616	2.586	2.580	2.584	2.594	2.605	2.614	2.611	2.600	2.584	2.553	2.506	2.465	2.441	2.436
40.0	2.609	2.587	2.556	2.532	2.524	2.529	2.541	2.551	2.556	2.554	2.545	2.528	2.493	2.448	2.407	2.381	2.373
37.5	2.533	2.516	2.497	2.480	2.471	2.474	2.485	2.493	2.498	2.494	2.488	2.473	2.440	2.394	2.352	2.327	2.316
35.0	2.462	2.453	2.441	2.429	2.420	2.419	2.428	2.436	2.439	2.436	2.432	2.418	2.388	2.344	2.302	2.276	2.260
34.0	2.434	2.428	2.419	2.408	2.400	2.397	2.404	2.412	2.414	2.413	2.409	2.398	2.368	2.325	2.283	2.257	2.239
33.0	2.406	2.403	2.397	2.388	2.379	2.375	2.380	2.388	2.390	2.388	2.387	2.377	2.349	2.307	2.265	2.238	2.220
32.0	2.378	2.378	2.375	2.367	2.358	2.353	2.356	2.363	2.365	2.365	2.364	2.356	2.330	2.289	2.249	2.221	2.203
31.0	2.351	2.353	2.353	2.347	2.338	2.331	2.333	2.337	2.341	2.342	2.342	2.336	2.311	2.273	2.234	2.205	2.184
30.0	2.324	2.329	2.331	2.326	2.318	2.310	2.310	2.313	2.315	2.318	2.320	2.316	2.292	2.258	2.220	2.191	2.169
29.0	2.298	2.306	2.309	2.305	2.297	2.290	2.288	2.289	2.291	2.294	2.298	2.296	2.275	2.243	2.208	2.179	2.157
28.0	2.273	2.282	2.286	2.282	2.277	2.270	2.266	2.265	2.266	2.270	2.275	2.275	2.259	2.230	2.197	2.168	2.147
27.0	2.249	2.260	2.265	2.261	2.257	2.252	2.245	2.242	2.243	2.246	2.251	2.255	2.244	2.218	2.188	2.160	2.138
26.0	2.227	2.238	2.245	2.242	2.239	2.234	2.226	2.219	2.219	2.223	2.229	2.235	2.229	2.208	2.181	2.154	2.132
25.0	2.208	2.220	2.228	2.225	2.223	2.217	2.207	2.197	2.195	2.199	2.207	2.215	2.216	2.199	2.175	2.150	2.128
24.0	2.192	2.205	2.213	2.211	2.208	2.201	2.188	2.176	2.171	2.175	2.183	2.195	2.203	2.192	2.171	2.147	2.127
23.0	2.179	2.193	2.202	2.199	2.194	2.186	2.169	2.153	2.146	2.149	2.160	2.174	2.190	2.186	2.169	2.148	2.129
22.0	2.168	2.184	2.194	2.190	2.182	2.171	2.150	2.130	2.122	2.124	2.135	2.152	2.175	2.181	2.169	2.151	2.134
21.0	2.158	2.176	2.190	2.185	2.171	2.155	2.129	2.106	2.097	2.099	2.111	2.130	2.161	2.177	2.172	2.157	2.142
20.0	2.147	2.168	2.186	2.182	2.162	2.138	2.105	2.080	2.072	2.073	2.086	2.108	2.147	2.174	2.176	2.165	2.150
19.0	2.136	2.160	2.182	2.182	2.157	2.119	2.078	2.051	2.040	2.043	2.058	2.085	2.133	2.172	2.180	2.174	2.160
18.0	2.124	2.149	2.177	2.184	2.156	2.103	2.046	2.012	2.001	2.007	2.026	2.062	2.121	2.171	2.187	2.184	2.170
17.0	2.110	2.135	2.169	2.185	2.159	2.093	2.018	1.980	1.975	1.982	2.002	2.046	2.114	2.173	2.195	2.195	2.181
16.0	2.092	2.118	2.157	2.185	2.165	2.096	2.018	1.983	1.982	1.987	2.002	2.047	2.116	2.176	2.203	2.205	2.193
15.0	2.074	2.101	2.147	2.187	2.175	2.114	2.053	2.028	2.029	2.031	2.037	2.068	2.125	2.178	2.208	2.213	2.203
14.0	2.057	2.086	2.139	2.188	2.187	2.143	2.106	2.097	2.100	2.100	2.097	2.106	2.143	2.181	2.206	2.216	2.211
13.0	2.042	2.076	2.132	2.185	2.197	2.176	2.166	2.170	2.176	2.176	2.167	2.159	2.170	2.186	2.201	2.214	2.215
12.0	2.030	2.070	2.130	2.182	2.208	2.217	2.230	2.244	2.251	2.250	2.237	2.221	2.209	2.200	2.198	2.204	2.209
10.0	2.025	2.089	2.165	2.226	2.282	2.334	2.373	2.392	2.396	2.390	2.376	2.354	2.320	2.277	2.237	2.206	2.188
8.0	2.117	2.179	2.258	2.337	2.411	2.469	2.507	2.527	2.534	2.529	2.509	2.484	2.447	2.397	2.346	2.300	2.267
6.0	2.251	2.299	2.375	2.459	2.537	2.596	2.635	2.658	2.664	2.655	2.635	2.608	2.566	2.514	2.467	2.420	2.384
4.0	2.365	2.422	2.497	2.575	2.652	2.717	2.756	2.779	2.787	2.778	2.757	2.726	2.676	2.620	2.574	2.530	2.488
2.0	2.469	2.531	2.602	2.672	2.753	2.823	2.864	2.888	2.897	2.889	2.866	2.829	2.773	2.713	2.668	2.627	2.577
0.0	2.558	2.622	2.688	2.754	2.836	2.910	2.957	2.981	2.989	2.984	2.963	2.920	2.852	2.777	2.719	2.662	2.584

KZZ (IN UNITS OF .00001 KMSQ/SEC)   FOR   OCTOBER

	SOUTH						LATITUDE (DEGREES)						NORTH			
ALT(KM)	80	70	60	50	40	30	20	10	0	10	20	30	40	50	60	70	80
50.0	3.289	3.289	3.289	2.280	3.082	.906	.206	.275	.236	.177	.156	.440	2.169	5.085	1.967	1.967	1.967
47.5	2.468	2.468	2.468	1.710	2.313	.679	.155	.207	.177	.133	.117	.330	1.627	3.815	1.476	1.476	1.476
45.0	1.851	1.851	1.851	1.283	1.735	.510	.116	.155	.133	.100	.088	.248	1.221	2.862	1.107	1.107	1.107
42.5	1.389	1.389	1.389	.963	1.302	.382	.087	.116	.100	.075	.066	.186	.916	2.147	.831	.831	.831
40.0	1.042	1.042	1.042	.722	.977	.287	.065	.087	.075	.056	.049	.139	.687	1.611	.623	.623	.623
37.5	.782	.782	.782	.542	.733	.215	.049	.065	.056	.042	.037	.105	.516	1.209	.468	.468	.468
35.0	.587	.587	.587	.406	.550	.162	.037	.049	.042	.032	.028	.078	.387	.907	.351	.351	.351
34.0	.523	.523	.523	.362	.490	.144	.033	.044	.038	.028	.025	.070	.345	.808	.313	.313	.313
33.0	.466	.466	.466	.323	.437	.128	.029	.039	.033	.025	.022	.062	.307	.721	.279	.279	.279
32.0	.415	.415	.415	.288	.389	.114	.026	.035	.030	.022	.020	.056	.274	.642	.249	.249	.249
31.0	.370	.370	.370	.257	.347	.102	.023	.031	.027	.020	.018	.050	.244	.573	.222	.222	.222
30.0	.330	.330	.330	.229	.309	.091	.021	.028	.024	.018	.016	.044	.218	.510	.197	.197	.197
29.0	.294	.294	.294	.204	.276	.081	.018	.025	.021	.016	.014	.039	.194	.455	.176	.176	.176
28.0	.262	.262	.262	.182	.246	.072	.016	.022	.019	.014	.012	.035	.173	.406	.157	.157	.157
27.0	.234	.234	.234	.162	.219	.064	.015	.020	.017	.013	.011	.031	.154	.362	.140	.140	.140
26.0	.208	.208	.208	.144	.195	.057	.013	.017	.015	.011	.010	.028	.137	.322	.125	.125	.125
25.0	.186	.186	.186	.129	.174	.051	.012	.016	.013	.010	.009	.025	.123	.287	.111	.111	.111
24.0	.166	.166	.166	.115	.155	.046	.010	.014	.012	.009	.008	.022	.109	.256	.099	.099	.099
23.0	.148	.148	.148	.102	.138	.041	.009	.012	.011	.008	.007	.020	.097	.228	.088	.088	.088
22.0	.132	.132	.132	.091	.123	.036	.008	.011	.009	.007	.006	.018	.087	.203	.079	.079	.079
21.0	.117	.117	.117	.081	.110	.032	.007	.010	.008	.006	.006	.016	.077	.181	.070	.070	.070
20.0	.105	.105	.105	.072	.098	.029	.007	.009	.008	.006	.005	.014	.069	.162	.063	.063	.063
19.0	.097	.097	.097	.083	.117	.069	.022	.013	.009	.009	.014	.034	.095	.157	.080	.080	.080
18.0	.089	.089	.089	.094	.137	.110	.038	.017	.011	.012	.023	.055	.122	.152	.098	.098	.098
17.0	.082	.082	.081	.105	.156	.150	.054	.021	.012	.015	.031	.075	.148	.147	.115	.115	.115
16.0	.080	.080	.080	.117	.172	.179	.067	.025	.014	.018	.040	.092	.172	.147	.129	.129	.129
15.0	.102	.102	.102	.133	.172	.157	.065	.031	.022	.019	.050	.088	.160	.161	.127	.127	.127
14.0	.125	.125	.125	.150	.173	.135	.063	.036	.029	.020	.060	.084	.147	.175	.125	.125	.125
13.0	.147	.147	.147	.167	.173	.112	.061	.041	.036	.021	.070	.080	.135	.189	.123	.123	.123
12.0	.165	.166	.168	.184	.173	.090	.078	.054	.048	.029	.089	.090	.122	.203	.121	.060	.058
10.0	.103	.103	.104	.136	.349	.145	.128	.095	.085	.057	.142	.144	.270	.195	.129	.089	.080
8.0	.118	.118	.119	.211	.545	.231	.209	.164	.152	.109	.227	.229	.378	.279	.153	.114	.105
6.0	.170	.220	.227	.345	.704	.369	.343	.285	.269	.210	.364	.366	.531	.424	.276	.175	.168
4.0	.347	.414	.427	.563	.908	.590	.561	.496	.477	.405	.583	.585	.748	.646	.486	.360	.347
2.0	.715	.784	.800	.919	1.168	.941	.917	.862	.846	.779	.934	.936	1.058	.984	.855	[illegible]	.722
0.0	1.500	1.500	1.500	1.500	1.500	1.500	1.500	1.500	1.500	1.500	1.500	1.500	1.500	1.500	1.500	1.500	1.500

KFZ (IN UNITS OF .001 KMSQ/SEC) FOR OCTOBER

ALT(KM)	SOUTH 80	70	60	50	40	30	20	LATITUDE (DEGREES) 10	0	10	20	30	40	NORTH 50	60	70	80
50.0	.267	.606	.808	.748	.914	.355	.065	.093	.044	.005	-.021	-.324	-1.350	-1.312	-1.312	-.984	-.433
47.5	.305	.692	.923	.855	.914	.355	.065	.097	.046	.005	-.021	-.324	-1.350	-1.312	-1.312	[illegible]	-.433
45.0	.343	.779	1.038	.962	.997	.372	.066	.101	.046	[illegible]	-.021	-.356	-1.538	-1.518	-1.518	[illegible]	-.501
42.5	.356	.809	1.079	1.000	1.018	.329	.058	.094	.043	.005	-.017	-.329	-1.471	-1.534	-1.534	-1.150	-.506
40.0	.369	.840	1.120	1.037	1.039	.287	.051	.087	.039	.005	-.013	-.301	-1.404	-1.550	-1.550	-1.162	-.511
37.5	.377	.856	1.142	1.058	1.100	.256	.048	.080	.036	.004	-.011	-.236	-1.367	-1.442	-1.442	-1.081	-.476
35.0	.384	.872	1.163	1.078	1.161	.224	.044	.073	.033	.003	-.008	-.171	-1.33[illegible]	-1.334	-1.334	-1.001	-.440
34.0	.389	.883	1.177	1.092	1.131	.228	.044	.074	.033	.003	-.007	-.157	-1.279	-1.336	-1.336	-1.002	-.441
33.0	.393	.894	1.192	1.105	1.100	.231	.044	.075	.033	.003	-.006	-.143	-1.227	-1.338	-1.338	-1.004	-.442
32.0	.398	.904	1.206	1.118	1.069	.235	.044	.077	.033	.003	-.006	-.128	-1.176	-1.340	-1.340	-1.005	-.442
31.0	.403	.915	1.220	1.131	1.038	.238	.044	.078	.034	.003	-.005	-.114	-1.124	-1.342	-1.342	-1.007	-.443
30.0	.407	.926	1.234	1.144	1.008	.242	.044	.079	.034	.003	-.004	-.099	-1.073	-1.344	-1.344	-1.008	-.443
29.0	.395	.898	1.197	1.110	.984	.251	.046	.081	.036	.003	-.005	-.107	-1.029	-1.340	-1.340	-1.005	-.442
28.0	.383	.870	1.160	1.076	.961	.260	.047	.084	.038	.003	-.006	-.115	-.984	-1.336	-1.336	-1.002	-.441
27.0	.371	.842	1.123	1.042	.937	.269	.049	.086	.040	.003	-.007	-.123	-.940	-1.332	-1.332	-.999	-.440
26.0	.358	.815	1.086	1.007	.914	.278	.050	.088	.042	.004	-.008	-.131	-.896	-1.328	-1.328	-.996	-.438
25.0	.346	.787	1.049	.973	.891	.287	.052	.091	.044	.004	-.009	-.139	-.852	-1.324	-1.324	-.993	-.437
24.0	.343	.778	1.038	.965	.867	.296	.053	.093	.046	.004	-.009	-.147	-.807	-1.315	-1.315	-.987	-.434
23.0	.339	.770	1.027	.956	.844	.305	.055	.095	.048	.004	-.010	-.155	-.763	-1.306	-1.306	-.980	-.431
22.0	.335	.762	1.016	.948	.820	.314	.056	.098	.050	.004	-.011	-.163	-.719	-1.297	-1.297	-.973	-.428
21.0	.332	.754	1.005	.940	.797	.323	.058	.100	.051	.004	-.012	-.171	-.674	-1.288	-1.288	-.966	-.425
20.0	.328	.745	.994	.931	.773	.332	.060	.102	.053	.004	-.013	-.179	-.630	-1.279	-1.279	-.959	-.422
19.0	.355	.806	1.075	1.004	.974	.692	.218	.144	.018	-.037	-.110	-.393	-.862	-1.322	-1.322	-.991	-.436
18.0	.382	.867	1.157	1.077	1.175	1.053	.376	.186	-.017	-.079	-.208	-.607	-1.094	-1.364	-1.364	-1.023	-.450
17.0	.409	.928	1.238	1.150	1.376	1.413	.534	.228	-.053	-.120	-.305	-.821	-1.326	-1.407	-1.407	-1.055	-.464
16.0	.445	1.012	1.350	1.251	1.564	1.562	.622	.241	-.060	-.142	-.373	-.943	-1.498	-1.469	-1.469	-1.102	-.485
15.0	.549	1.249	1.665	1.554	1.703	.948	.426	.136	-.081	-.083	-.322	-.666	-1.430	-1.705	-1.705	-1.279	-.563
14.0	.673	1.530	2.040	1.907	1.841	.363	.230	.045	-.082	-.017	-.270	-.410	-1.362	-1.944	-1.944	-1.458	-.642
13.0	.801	1.820	2.426	2.268	1.980	-.100	.038	-.010	-.083	.053	-.214	-.213	-1.294	-2.185	-2.185	-1.639	-.721
12.0	.932	2.118	2.823	2.639	2.118	-.100	-.083	-.040	-.087	.100	-.156	-.134	-1.226	-2.426	-2.426	-1.820	-.801
10.0	-.062	.064	.365	-.099	-.100	-.100	-.100	-.100	.045	.088	.100	.100	.100	.100	.100	.100	.100
8.0	-.100	-.067	-.100	-.100	-.100	-.100	-.100	-.100	.039	.056	.100	.100	.100	.100	.100	.100	.100
6.0	.064	-.016	-.100	-.100	-.100	-.100	-.100	-.078	-.004	.057	.100	.100	.100	.100	.058	.084	-.154
4.0	.499	.538	1.199	.961	-.100	-.100	-.100	-.046	.032	.090	.100	.100	.089	-.563	-1.363	-.700	-.458
2.0	.607	1.030	2.091	2.001	1.213	.381	-.100	-.100	.060	.079	.098	-.120	-.785	-1.932	-2.153	-1.109	-.681
0.0	.443	.829	1.697	1.715	1.189	.765	.052	-.082	.097	.094	.031	-.491	-.903	-1.695	-1.676	-.823	-.510

KFF (IN UNITS OF KMSQ/SEC) FOR OCTOBER

ALT(KM)	SOUTH 80	70	60	50	40	30	20	LATITUDE (DEGREES) 10	0	10	20	30	40	NORTH 50	60	70	80
50.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
47.5	3.804	3.187	3.414	2.989	2.046	1.319	1.070	.880	.618	.542	.982	1.748	3.246	2.783	3.965	4.959	4.979
45.0	3.086	2.721	3.172	2.762	1.820	1.114	.861	.745	.496	.406	.813	1.563	3.041	2.667	3.628	4.715	4.793
42.5	2.479	2.219	2.887	2.501	1.621	.881	.682	.613	.408	.329	.587	1.275	2.562	2.349	3.038	4.508	4.611
40.0	1.871	1.715	2.603	2.239	1.422	.648	.502	.481	.319	.252	.362	.986	2.083	2.030	2.449	4.300	4.430
37.5	1.557	1.433	2.279	2.051	1.345	.534	.426	.400	.264	.190	.266	.719	1.832	1.705	1.999	3.659	3.874
35.0	1.242	1.151	1.955	1.863	1.269	.420	.350	.319	.209	.128	.171	.451	1.581	1.379	1.550	3.018	3.319
34.0	1.170	1.080	1.871	1.821	1.199	.412	.338	.312	.203	.119	.150	.405	1.478	1.334	1.445	2.772	3.035
33.0	1.098	1.011	1.787	1.778	1.130	.405	.327	.306	.197	.110	.129	.359	1.374	1.289	1.341	2.526	2.751
32.0	1.025	.941	1.702	1.736	1.061	.397	.315	.300	.190	.100	.108	.312	1.270	1.244	1.237	2.281	2.467
31.0	.953	.872	1.618	1.693	.992	.390	.303	.294	.184	.091	.087	.266	1.166	1.199	1.133	2.034	2.184
30.0	.880	.802	1.534	1.650	.923	.382	.292	.287	.178	.082	.067	.219	1.063	1.153	1.028	1.789	1.900
29.0	.982	.913	1.512	1.572	.885	.383	.292	.286	.180	.094	.077	.227	1.004	1.123	1.053	1.739	1.838
28.0	1.084	1.023	1.491	1.493	.847	.384	.292	.286	.183	.106	.088	.234	.944	1.093	1.077	1.689	1.776
27.0	1.185	1.134	1.469	1.414	.809	.385	.293	.285	.186	.118	.099	.242	.884	1.063	1.102	1.639	1.715
26.0	1.287	1.245	1.448	1.335	.771	.386	.293	.284	.188	.129	.109	.249	.825	1.033	1.126	1.589	1.654
25.0	1.389	1.356	1.426	1.257	.733	.388	.293	.283	.191	.141	.120	.256	.765	1.002	1.151	1.539	1.592
24.0	1.490	1.467	1.405	1.178	.696	.389	.294	.282	.194	.153	.130	.264	.706	.972	1.175	1.489	1.531
23.0	1.592	1.577	1.384	1.099	.658	.390	.294	.281	.196	.165	.141	.272	.646	.942	1.199	1.440	1.469
22.0	1.693	1.688	1.362	1.020	.620	.391	.294	.280	.198	.177	.152	.279	.586	.911	1.224	1.389	1.408
21.0	1.795	1.799	1.341	.942	.583	.392	.294	.279	.201	.189	.163	.287	.526	.881	1.248	1.339	1.346
20.0	1.897	1.910	1.319	.863	.545	.393	.294	.278	.203	.200	.174	.294	.467	.851	1.273	1.290	1.265
19.0	1.783	1.876	1.377	.957	.723	.623	.448	.373	.249	.255	.273	.441	.625	.946	1.261	1.265	1.254
18.0	1.670	1.843	1.434	1.051	.902	.853	.603	.468	.295	.310	.371	.587	.784	1.042	1.250	1.239	1.222
17.0	1.556	1.809	1.492	1.146	1.081	1.083	.757	.563	.341	.365	.470	.733	.943	1.138	1.238	1.214	1.191
16.0	1.466	1.795	1.586	1.315	1.345	1.397	.947	.658	.390	.423	.590	.931	1.182	1.326	1.295	1.229	1.194
15.0	1.475	1.859	1.826	1.787	1.951	1.986	1.283	.756	.452	.495	.797	1.338	1.743	1.831	1.628	1.401	1.333
14.0	1.483	1.924	2.066	2.257	2.556	2.584	1.619	.854	.514	.567	1.003	1.744	2.304	2.437	1.960	1.573	1.472
13.0	1.492	1.988	2.306	2.730	3.162	3.183	1.955	.952	.576	.639	1.209	2.150	2.865	2.992	2.293	1.746	1.612
12.0	1.500	2.053	2.545	3.201	3.767	3.781	2.290	1.049	.638	.711	1.416	2.556	3.426	3.548	2.625	1.918	1.751
10.0	2.298	3.101	3.988	4.774	4.597	3.428	1.861	.853	.477	.541	1.089	2.234	3.660	4.365	3.630	2.781	2.670
8.0	2.575	3.405	4.153	4.686	4.005	2.502	1.263	.601	.300	.363	.725	1.616	3.032	3.935	3.515	2.899	2.855
6.0	1.994	2.603	2.979	3.196	2.601	1.590	.761	.372	.181	.246	.466	1.033	1.921	2.634	2.407	2.117	2.170
4.0	1.279	1.633	1.919	2.055	1.678	1.110	.500	.263	.145	.207	.347	.724	1.201	1.668	1.555	1.329	1.379
2.0	.841	.978	1.187	1.315	1.128	.779	.361	.205	.143	.182	.278	.528	.792	1.064	1.043	.838	.849
0.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

V (IN UNITS OF .001 KM/SEC)   FOR   OCTOBER

ALT(KM)	SOUTH 80	70	60	50	40	30	20	LATITUDE (DEGREES) 10	0	10	20	30	40	NORTH 50	60	70	80
50.0	.091	.134	.144	.133	.065	-.032	-.057	-.016	.021	.028	.034	-.057	-.143	-.136	-.132	-.128	-.104
47.5	.000	.012	-.113	-.213	-.339	-.458	-.465	-.403	-.330	-.257	-.243	-.303	-.367	-.410	-.445	-.419	-.277
45.0	-.011	.017	-.055	-.145	-.257	-.352	-.371	-.322	-.266	-.211	-.181	-.219	-.283	-.325	-.330	-.273	-.147
42.5	.064	.098	.102	.067	-.022	-.095	-.126	-.097	-.094	-.084	-.067	-.112	-.212	-.266	-.224	-.128	-.037
40.0	.118	.159	.213	.216	.159	.122	.091	.081	.046	.015	-.018	-.073	-.182	-.289	-.229	-.055	.077
37.5	.082	.145	.217	.201	.168	.170	.165	.125	.072	.009	-.049	-.075	-.127	-.274	-.282	-.086	.136
35.0	.021	.112	.189	.137	.083	.091	.105	.055	.009	-.052	-.093	-.073	-.065	-.213	-.336	-.207	.103
34.0	.011	.102	.178	.121	.049	.041	.051	.006	-.026	-.073	-.094	-.062	-.044	-.183	-.338	-.229	.123
33.0	.012	.089	.157	.107	.026	-.011	-.011	-.046	-.059	-.087	-.086	-.052	-.032	-.164	-.322	-.236	.082
32.0	.013	.070	.126	.088	.012	-.053	-.065	-.089	-.080	-.090	-.072	-.043	-.029	-.150	-.293	-.220	.062
31.0	.011	.050	.097	.074	.007	-.077	-.099	-.114	-.085	-.079	-.048	-.027	-.025	-.131	-.244	-.167	.091
30.0	.004	.031	.071	.060	.006	-.086	-.116	-.123	-.079	-.061	-.021	-.010	-.022	-.114	-.192	-.129	.037
29.0	-.004	.020	.056	.047	.003	-.086	-.117	-.113	-.063	-.037	.007	.009	-.014	-.089	-.139	-.079	.050
28.0	-.006	.024	.054	.042	-.003	-.084	-.109	-.090	-.039	-.009	.038	.035	.003	-.057	-.096	-.038	.093
27.0	.002	.043	.063	.041	-.010	-.075	-.090	-.052	-.004	.030	.078	.075	.045	-.004	-.043	.018	.193
26.0	.016	.072	.079	.045	-.013	-.069	-.078	-.024	.019	.059	.105	.107	.084	.039	-.012	.049	.260
25.0	.035	.099	.096	.050	-.012	-.067	-.080	-.020	.020	.065	.103	.111	.099	.053	-.015	.035	.241
24.0	.050	.121	.112	.060	-.004	-.045	-.066	-.013	.027	.077	.102	.115	.116	.077	.008	.065	.301
23.0	.056	.135	.126	.077	.017	-.011	-.042	-.006	.034	.084	.093	.106	.115	.087	.029	.096	.345
22.0	.053	.138	.138	.101	.047	.014	-.032	-.016	.026	.071	.064	.068	.076	.057	.014	.074	.263
21.0	.041	.135	.151	.126	.071	.028	-.027	-.024	.023	.063	.047	.037	.039	.029	.012	.074	.219
20.0	.025	.128	.163	.141	.081	.035	-.021	-.025	.033	.074	.051	.023	.017	.012	.027	.103	.240
19.0	.009	.122	.169	.142	.093	.057	-.022	-.040	.052	.113	.072	.015	-.006	-.008	.035	.122	.251
18.0	-.010	.123	.192	.165	.134	.112	-.047	-.105	.119	.267	.178	.048	.001	.009	.083	.198	.398
17.0	-.015	.103	.181	.171	.145	.165	-.126	-.260	.104	.392	.341	.152	.039	.036	.149	.295	.556
16.0	-.002	.048	.097	.111	.087	.160	-.280	-.515	-.126	.293	.421	.250	.037	-.033	.108	.242	.357
15.0	-.001	-.017	-.003	.018	.005	.080	-.469	-.829	-.495	.017	.347	.248	-.055	[illegible]	-.098	-.030	-.252
14.0	-.031	-.060	-.059	-.043	-.047	.009	-.542	-1.033	-.771	-.205	.231	.203	-.135	-.368	-.252	-.203	-.584
13.0	-.081	-.066	-.042	-.031	-.024	-.018	-.470	-1.068	-.821	-.229	.175	.164	-.152	-.368	-.250	-.148	-.383
12.0	-.106	-.052	.003	.031	.032	-.025	-.353	-.957	-.706	-.133	.181	.135	-.146	-.310	-.197	-.058	-.115
10.0	-.060	-.031	.031	.109	.073	-.034	-.206	-.553	-.382	.011	.172	.100	-.120	-.223	-.144	-.028	-.001
8.0	-.022	-.025	.019	.086	.053	-.049	-.143	-.212	-.133	.044	.095	.070	-.082	-.172	-.121	[illegible]	-.012
6.0	-.010	-.020	.000	.009	.012	-.049	-.044	-.008	.008	[illegible]	037	.046	-.014	-.073	-.049	[illegible]	019
4.0	.020	-.005	-.018	-.048	-.025	-.019	.109	.212	.138	-.007	-.049	-.028	.053	.085	.049	.008	-.004
2.0	.033	.012	-.039	-.076	-.054	.028	.259	.530	.330	-.033	-.202	-.143	.079	.205	.124	-.000	-.018
0.0	.008	.003	-.056	-.087	-.066	.082	.369	.573	.236	-.206	-.247	-.036	.134	.206	.103	.004	-.052

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TWO-DIMENSIONAL DESCRIPTION OF THE NATURAL ATMOSPHERE INCLUDING--ETC(U)

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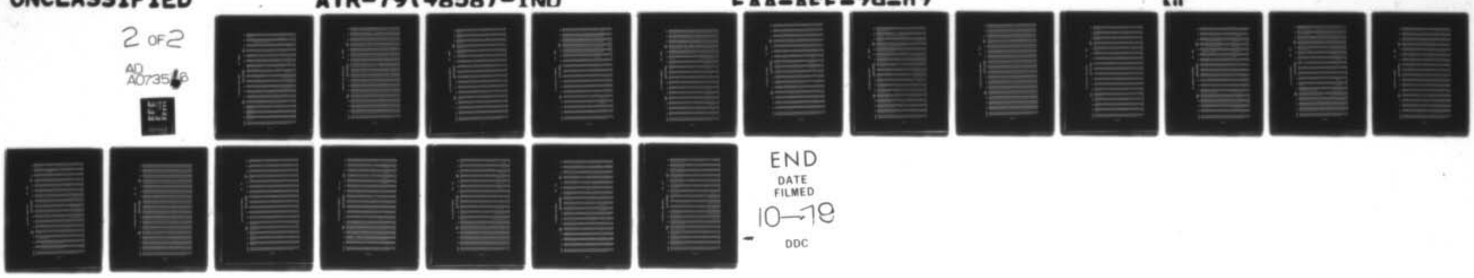

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W (IN UNITS OF .000001 KM/SEC) FOR OCTOBER

	SOUTH							LATITUDE (DEGREES)						NORTH			
ALT(KM)	80	70	60	50	40	30	20	10	0	10	20	30	40	50	60	70	80
50.0	-3.380	-3.510	-1.860	-.249	.712	.904	.520	.687	.426	-.296	-.084	.178	-.203	-.025	-.337	-.192	1.130
47.5	-2.435	-2.685	-1.700	-.423	.181	.413	.428	.641	.393	-.103	-.093	.003	-.121	.147	.026	.440	1.855
45.0	-1.790	-1.990	-1.550	-.631	-.223	.074	.325	.570	.447	.051	-.074	-.061	-.054	.218	.290	.853	2.090
42.5	-1.230	-1.390	-1.230	-.645	-.390	-.101	.231	.494	.365	.123	-.001	-.134	-.089	.260	.442	.943	1.805
40.0	-.508	-.752	-.695	-.450	-.419	-.149	.125	.387	.198	.096	-.032	-.244	-.226	.287	.636	.934	1.320
37.5	.032	-.259	-.228	-.224	-.299	-.098	.041	.216	.044	-.022	-.132	-.281	-.334	.159	.901	1.060	.802
35.0	.263	.100	.047	-.160	-.185	.001	.019	.032	-.076	-.155	-.152	-.176	-.317	-.114	.918	1.300	.564
34.0	.299	.213	.115	-.178	-.178	.025	.013	-.025	-.096	-.180	-.131	-.116	-.293	-.224	.833	1.410	.595
33.0	.321	.299	.167	-.201	-.193	.024	.006	-.064	-.097	-.184	-.096	-.065	-.269	-.319	.728	1.490	.662
32.0	.332	.353	.203	-.215	-.223	-.007	.001	-.083	-.079	-.173	-.052	-.030	-.246	-.395	.630	1.530	.726
31.0	.328	.375	.225	-.218	-.254	-.059	-.004	-.086	-.045	-.151	-.008	-.012	-.229	-.445	.551	1.530	.760
30.0	.309	.373	.236	-.208	-.280	-.120	-.010	-.077	.001	-.123	.033	-.012	-.217	-.469	.495	1.490	.750
29.0	.277	.358	.239	-.194	-.295	-.177	-.015	-.059	.048	-.092	.066	-.025	-.212	-.466	.456	1.400	.700
28.0	.243	.341	.235	-.181	-.303	-.223	-.015	-.031	.088	-.062	.091	-.048	-.211	-.446	.418	1.300	.622
27.0	.221	.333	.224	-.175	-.308	-.250	-.008	.006	.115	-.029	.109	-.072	-.214	-.420	.370	1.190	.533
26.0	.224	.339	.206	-.176	-.314	-.250	.006	.053	.129	.006	.120	-.091	-.217	-.404	.309	1.100	.447
25.0	.253	.358	.183	-.184	-.320	-.250	.021	.102	.134	.043	.122	-.098	-.219	-.400	.234	1.020	.368
24.0	.305	.386	.159	-.195	-.324	-.250	.026	.146	.137	.078	.114	-.090	-.215	-.404	.157	.957	.293
23.0	.366	.420	.140	-.201	-.321	-.230	.016	.178	.142	.106	.093	-.071	-.206	-.405	.088	.900	.217
22.0	.423	.457	.132	-.194	-.310	-.210	-.008	.192	.151	.120	.063	-.051	-.191	-.392	.038	.844	.136
21.0	.465	.498	.141	-.173	-.297	-.210	-.041	.192	.164	.120	.028	-.038	-.171	-.362	.014	.782	.054
20.0	.488	.544	.166	-.148	-.291	-.210	-.070	.185	.182	.111	-.006	-.039	-.148	-.320	.020	.716	-.020
19.0	.491	.591	.199	-.129	-.287	-.210	-.097	.179	.210	.098	-.046	-.056	-.128	-.271	.052	.652	-.074
18.0	.482	.636	.228	-.113	-.257	-.210	-.158	.181	.280	.090	-.116	-.095	-.112	-.217	.106	.590	-.101
17.0	.459	.703	.285	-.083	-.213	-.230	-.309	.219	.537	.097	-.286	-.194	-.107	-.153	.158	.538	-.102
16.0	.424	.707	.322	-.044	-.171	-.230	-.607	.248	.885	.221	-.380	-.372	-.174	-.098	.240	.462	-.083
15.0	.368	.621	.314	-.010	-.144	-.250	-1.040	.221	1.230	.493	-.301	-.579	-.332	-.064	.378	.370	-.056
14.0	.282	.484	.266	.006	-.133	-.330	-1.530	.088	1.530	.866	-.078	-.749	-.550	-.050	.563	.299	-.033
13.0	.165	.372	.216	.008	-.123	-.400	-1.940	-.173	1.810	1.240	.155	-.853	-.760	-.037	.749	.284	-.022
12.0	.038	.336	.202	.016	-.109	-.500	-2.200	-.515	2.140	1.540	.282	-.921	-.909	-.004	.888	.324	-.024
10.0	-.138	.348	.274	.094	-.162	-.660	-2.300	-1.070	2.640	1.880	.309	-1.070	-1.060	.089	1.000	.421	-.058
8.0	-.162	.295	.342	.193	-.277	-.740	-2.100	-1.040	2.530	1.900	.218	-1.050	-1.140	.142	1.000	.474	-.126
6.0	-.170	.234	.352	.206	-.312	-.753	-1.740	-.758	2.140	1.660	.132	-.883	-1.150	.130	.983	.507	-.226
4.0	-.151	.162	.277	.129	-.224	-.658	-1.270	-.600	1.700	1.300	.159	-.722	-.969	.060	.830	.421	-.249
2.0	-.065	.067	.162	.052	-.114	-.391	-.683	-.407	1.020	.759	.124	-.452	-.518	.003	.437	.217	-.121
0.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

T (IN UNITS OF 100. DEGREES KELVIN) FOR JANUARY

ALT(KM)	SOUTH 80	70	60	50	40	30	20	10	LATITUDE (DEGREES) 0	10	20	30	40	NORTH 50	60	70	80
50.0	2.900	2.851	2.801	2.770	2.753	2.738	2.724	2.715	2.717	2.715	2.700	2.664	2.615	2.564	2.498	2.476	2.473
47.5	2.871	2.838	2.798	2.767	2.745	2.727	2.711	2.703	2.708	2.711	2.696	2.662	2.614	2.532	2.457	2.431	2.440
45.0	2.813	2.794	2.763	2.732	2.705	2.690	2.683	2.679	2.685	2.687	2.672	2.639	2.582	2.487	2.411	2.381	2.398
42.5	2.742	2.727	2.703	2.675	2.655	2.645	2.643	2.645	2.651	2.651	2.636	2.603	2.538	2.443	2.366	2.335	2.351
40.0	2.668	2.657	2.639	2.615	2.598	2.592	2.595	2.599	2.604	2.602	2.586	2.552	2.485	2.393	2.322	2.290	2.303
37.5	2.598	2.589	2.575	2.556	2.539	2.533	2.537	2.542	2.544	2.539	2.525	2.492	2.429	2.339	2.270	2.245	2.252
35.0	2.537	2.529	2.516	2.497	2.478	2.470	2.473	2.477	2.477	2.472	2.460	2.431	2.371	2.287	2.221	2.197	2.197
34.0	2.515	2.507	2.493	2.472	2.454	2.444	2.446	2.449	2.450	2.444	2.433	2.405	2.348	2.268	2.202	2.176	2.176
33.0	2.494	2.486	2.471	2.449	2.428	2.418	2.417	2.420	2.422	2.416	2.406	2.381	2.326	2.251	2.186	2.156	2.155
32.0	2.475	2.466	2.450	2.426	2.403	2.390	2.387	2.390	2.393	2.387	2.379	2.355	2.304	2.235	2.170	2.136	2.133
31.0	2.458	2.447	2.430	2.404	2.378	2.363	2.358	2.360	2.363	2.359	2.352	2.329	2.282	2.220	2.157	2.119	2.111
30.0	2.442	2.430	2.411	2.383	2.354	2.337	2.330	2.329	2.333	2.331	2.325	2.305	2.261	2.206	2.145	2.104	2.094
29.0	2.426	2.415	2.393	2.363	2.331	2.311	2.301	2.299	2.302	2.302	2.298	2.280	2.244	2.197	2.136	2.092	2.079
28.0	2.412	2.399	2.377	2.344	2.309	2.284	2.272	2.270	2.272	2.273	2.270	2.256	2.229	2.188	2.130	2.083	2.068
27.0	2.400	2.385	2.361	2.325	2.285	2.259	2.244	2.241	2.242	2.243	2.240	2.231	2.215	2.179	2.125	2.077	2.060
26.0	2.389	2.373	2.347	2.307	2.263	2.233	2.217	2.212	2.213	2.214	2.213	2.209	2.202	2.173	2.121	2.074	2.057
25.0	2.380	2.363	2.336	2.291	2.243	2.209	2.191	2.184	2.182	2.185	2.188	2.186	2.192	2.166	2.117	[illegible]	2.055
24.0	2.372	2.355	2.326	2.278	2.224	2.186	2.165	2.155	2.152	[illegible]	2.160	2.164	2.182	[illegible]	2.115	[illegible]	2.055
23.0	2.364	2.348	2.318	2.265	2.207	2.164	2.139	2.127	2.121	2.127	2.131	2.143	2.171	2.157	2.116	2.074	2.057
22.0	2.359	2.342	2.311	2.254	2.190	2.142	2.113	2.098	2.091	2.097	2.103	2.123	2.161	2.155	2.119	2.081	2.062
21.0	2.353	2.337	2.304	2.244	2.175	2.121	2.085	2.068	2.061	2.065	2.075	2.104	2.151	2.154	2.122	2.088	2.069
20.0	2.345	2.331	2.298	2.236	2.163	2.100	2.057	2.036	2.030	2.034	2.048	2.086	[illegible]	2.153	2.125	2.097	2.077
19.0	2.338	2.324	2.291	2.229	2.152	2.082	2.031	2.004	1.997	2.005	2.025	2.073	2.135	2.153	2.127	2.103	2.086
18.0	2.330	2.318	2.285	2.224	2.144	2.068	2.010	1.977	1.969	1.982	2.009	2.064	2.130	2.152	2.129	2.109	2.093
17.0	2.319	2.310	2.280	2.222	2.140	2.060	1.996	1.962	1.958	1.975	2.004	2.060	2.128	2.152	2.130	2.114	2.099
16.0	2.307	2.299	2.273	2.219	2.140	2.060	2.003	1.978	1.980	1.993	2.016	2.064	2.128	2.148	2.131	2.117	2.105
15.0	2.294	2.287	2.264	2.216	2.144	2.077	2.039	2.028	2.034	2.040	2.053	2.082	2.132	2.146	2.133	2.121	2.111
14.0	2.280	2.274	2.254	2.212	2.155	2.114	2.098	2.099	2.103	2.105	2.107	2.110	2.140	2.147	2.136	2.126	2.117
13.0	2.264	2.262	2.245	2.210	2.177	2.168	2.167	2.171	2.175	2.179	2.169	2.151	2.154	2.151	2.141	2.133	2.124
12.0	2.243	2.248	2.238	2.214	2.211	2.229	2.238	2.244	2.247	2.250	2.234	2.206	2.177	2.158	2.145	2.139	2.131
10.0	2.186	2.210	2.242	2.277	2.325	2.367	2.383	2.389	2.388	2.382	2.368	2.330	2.265	2.202	2.163	2.152	2.144
8.0	2.194	2.232	2.309	2.402	2.470	2.504	2.519	2.525	2.525	2.516	2.493	2.449	2.380	2.297	2.229	2.193	2.179
6.0	2.309	2.360	2.441	2.530	2.594	2.629	2.647	2.656	2.654	2.643	2.618	2.571	2.498	2.417	2.344	2.295	2.268
4.0	2.423	2.488	2.568	2.639	2.699	2.743	2.768	2.778	2.779	2.766	2.736	2.681	2.605	2.525	2.456	2.404	2.373
2.0	2.525	2.591	2.658	2.721	2.788	2.844	2.873	2.886	2.891	2.879	2.845	2.777	2.695	2.618	2.555	2.502	2.452
0.0	2.604	2.661	2.718	2.781	2.860	2.932	2.965	2.980	2.986	2.978	2.939	2.858	2.762	2.673	2.591	2.509	2.427

KZZ (IN UNITS OF .00001 KMSQ/SEC) FOR JANUARY

	SOUTH							LATITUDE (DEGREES)						NORTH			
ALT(KM)	80	70	60	50	40	30	20	10	0	10	20	30	40	50	60	70	80
50.0	1.262	1.262	1.262	1.446	.444	.234	.201	.188	.298	.184	.203	.964	4.893	5.488	2.668	2.668	2.668
47.5	.947	.947	.947	1.085	.333	.175	.151	.141	.224	.138	.152	.723	3.671	4.117	2.001	2.001	2.001
45.0	.710	.710	.710	.814	.250	.131	.113	.106	.168	.103	.114	.543	2.754	3.089	1.501	1.501	1.501
42.5	.533	.533	.533	.611	.188	.099	.085	.079	.126	.078	.086	.407	2.066	2.317	1.126	1.126	1.126
40.0	.400	.400	.400	.458	.141	.074	.064	.060	.095	.058	.064	.305	1.550	1.739	.845	.845	.845
37.5	.300	.300	.300	.344	.106	.056	.048	.045	.071	.044	.048	.229	1.163	1.304	.634	.634	.634
35.0	.225	.225	.225	.258	.079	.042	.036	.034	.053	.033	.036	.172	.873	.979	.476	.476	.476
34.0	.201	.201	.201	.230	.071	.037	.032	.030	.047	.029	.032	.153	.778	.872	.424	.424	.424
33.0	.179	.179	.179	.205	.063	.033	.028	.027	.042	.026	.029	.137	.693	.778	.378	.378	.378
32.0	.159	.159	.159	.183	.056	.030	.025	.024	.038	.023	.026	.122	.618	.693	.337	.337	.337
31.0	.142	.142	.142	.163	.050	.026	.023	.021	.034	.021	.023	.109	.551	.618	.300	.300	.300
30.0	.127	.127	.127	.145	.045	.023	.020	.019	.030	.018	.020	.097	.491	.551	.268	.268	.268
29.0	.113	.113	.113	.129	.040	.021	.018	.017	.027	.016	.018	.086	.438	.491	.239	.239	.239
28.0	.101	.101	.101	.115	.035	.019	.016	.015	.024	.015	.016	.077	.390	.438	.213	.213	.213
27.0	.090	.090	.090	.103	.032	.017	.014	.013	.021	.013	.014	.069	.348	.390	.190	.190	.190
26.0	.080	.080	.080	.092	.028	.015	.013	.012	.019	.012	.013	.061	.310	.348	.169	.169	.169
25.0	.071	.071	.071	.082	.025	.013	.011	.011	.017	.010	.011	.054	.276	.310	.151	.151	.151
24.0	.064	.064	.064	.073	.022	.012	.010	.009	.015	.009	.010	.049	.246	.276	.134	.134	.134
23.0	.057	.057	.057	.065	.020	.010	.009	.008	.013	.008	.009	.043	.220	.246	.120	.120	.120
22.0	.050	.050	.050	.058	.018	.009	.008	.008	.012	.007	.008	.039	.196	.220	.107	.107	.107
21.0	.045	.045	.045	.052	.016	.008	.007	.007	.011	.007	.007	.034	.175	.196	.095	.095	.095
20.0	.040	.040	.040	.046	.014	.007	.006	.006	.009	.006	.006	.031	.156	.175	.085	.085	.085
19.0	.041	.041	.042	.056	.045	.019	.016	.012	.010	.008	.019	.075	.161	.167	.089	.089	.089
18.0	.043	.043	.044	.066	.076	.031	.026	.017	.010	.010	.032	.120	.167	.159	.093	.093	.093
17.0	.044	.044	.046	.076	.107	.043	.036	.023	.010	.012	.044	.165	.173	.151	.097	.097	.097
16.0	.048	.048	.048	.086	.138	.056	.046	.028	.011	.016	.056	.196	.174	.143	.101	.101	.101
15.0	.064	.064	.064	.113	.136	.055	.044	.027	.014	.026	.061	.171	.156	.139	.102	.102	.102
14.0	.080	.080	.080	.140	.135	.054	.041	.026	.017	.036	.056	.146	.139	.136	.103	.103	.103
13.0	.096	.096	.096	.167	.133	.053	.039	.026	.023	.047	.071	.121	.122	.132	.104	.104	.104
12.0	.054	.059	.140	.195	.131	.052	.052	.036	.032	.061	.090	.095	.105	.128	.106	.107	.107
10.0	.076	.072	.135	.177	.266	.091	.092	.067	.061	.104	.143	.151	.387	.125	.090	.090	.090
8.0	.102	.070	.155	.217	.380	.160	.160	.124	.115	.178	.229	.239	.506	.274	.095	.097	.097
6.0	.093	.090	.262	.352	.532	.280	.281	.231	.219	.303	.366	.378	.663	.415	.113	.102	.077
4.0	.212	.227	.468	.572	.748	.490	.491	.431	.416	.517	.586	.598	.869	.634	.267	.247	.210
2.0	.562	.581	.838	.926	1.057	.857	.858	.804	.790	.881	.937	.947	1.141	.973	.633	.605	.562
0.0	1.500	1.500	1.500	1.500	1.500	1.500	1.500	1.500	1.500	1.500	1.500	1.500	1.500	1.500	1.500	1.500	1.500

KFZ (IN UNITS OF .001 KMSQ/SEC) FOR JANUARY

				SOUTH				LATITUDE (DEGREES)						NORTH			
ALT(KM)	80	70	60	50	40	30	20	10	0	10	20	30	40	50	60	70	80
50.0	.046	.104	.138	.145	.026	.038	.024	.030	.014	.004	.011	-.547	-2.343	-1.930	-1.930	-1.447	-.637
47.5	.048	.109	.145	.153	.026	.038	.023	.029	.014	.003	.012	-.547	-2.343	-1.930	-1.930	-1.447	-.637
45.0	.050	.114	.152	.160	.025	.039	.022	.029	.014	.002	.012	-.581	-2.613	-2.220	-2.220	-1.665	-.732
42.5	.049	.111	.149	.157	.021	.039	.021	.028	.013	.002	.009	-.511	-2.589	-2.280	-2.280	-1.710	-.752
40.0	.048	.109	.145	.154	.017	.038	.020	.026	.012	.002	.007	-.440	-2.565	-2.340	-2.340	-1.755	-.772
37.5	.046	.104	.139	.148	.005	.042	.020	.027	.012	.002	.005	-.346	-2.637	-2.303	-2.303	-1.727	-.760
35.0	.043	.099	.132	.141	-.007	.046	.020	.027	.012	.002	.004	-.253	-2.709	-2.266	-2.266	-1.699	-.748
34.0	.044	.100	.133	.142	-.001	.045	.020	.027	.013	.002	.003	-.244	-2.606	-2.293	-2.293	-1.720	-.757
33.0	.044	.101	.134	.144	.006	.044	.020	.028	.013	.001	.003	-.236	-2.502	-2.321	-2.321	-1.741	-.766
32.0	.045	.101	.135	.145	.012	.043	.020	.028	.013	.001	.002	-.227	-2.398	-2.349	-2.349	-1.762	-.775
31.0	.045	.102	.136	.146	.018	.042	.020	.029	.014	.001	.002	-.219	-2.295	-2.377	-2.377	-1.783	-.784
30.0	.045	.103	.137	.147	.024	.042	.020	.029	.014	.001	.001	-.210	-2.191	-2.405	-2.405	-1.804	-.794
29.0	.051	.116	.154	.164	.036	.044	.022	.030	.014	.001	.002	-.224	-2.105	-2.350	-2.350	-1.762	-.775
28.0	.056	.128	.171	.180	.048	.047	.023	.031	.014	.002	.003	-.237	-2.018	-2.294	-2.294	-1.721	-.757
27.0	.062	.141	.188	.197	.060	.049	.025	.032	.014	.002	.003	-.250	-1.931	-2.239	-2.239	-1.679	-.739
26.0	.068	.153	.205	.213	.072	.052	.027	.033	.014	.003	.004	-.263	-1.844	-2.184	-2.184	-1.638	-.721
25.0	.073	.166	.221	.230	.083	.055	.028	.034	.014	.003	.005	-.276	-1.758	-2.129	-2.129	-1.597	-.703
24.0	.078	.177	.236	.244	.095	.057	.030	.035	.014	.004	.005	-.290	-1.671	-2.131	-2.131	-1.598	-.703
23.0	.083	.188	.251	.259	.107	.060	.031	.036	.014	.004	.006	-.303	-1.584	-2.134	-2.134	-1.600	-.704
22.0	.088	.199	.266	.273	.119	.062	.033	.037	.014	.005	.006	-.316	-1.498	-2.136	-2.136	-1.602	-.705
21.0	.092	.210	.280	.287	.131	.065	.035	.037	.015	.005	.007	-.329	-1.411	-2.138	-2.138	-1.604	-.706
20.0	.097	.221	.295	.302	.142	.068	.036	.038	.015	.006	.008	-.343	-1.324	-2.141	-2.141	-1.606	-.706
19.0	.129	.292	.390	.398	.367	.195	.127	.095	.036	-.026	-.173	-.801	-1.466	-2.127	-2.127	-1.596	-.702
18.0	.160	.363	.484	.493	.591	.322	.218	.151	.058	-.057	-.355	-1.260	-1.607	-2.114	-2.114	-1.586	-.698
17.0	.191	.434	.579	.589	.816	.449	.308	.207	.080	-.088	-.536	-1.718	-1.748	-2.101	-2.101	-1.576	-.693
16.0	.237	.538	.718	.729	.995	.532	.373	.244	.080	-.090	-.630	-1.934	-1.845	-2.082	-2.082	-1.561	-.687
15.0	.335	.760	1.014	1.026	.994	.420	.331	.201	.036	.023	-.379	-1.131	-1.763	-2.414	-2.414	-1.810	-.796
14.0	.431	.979	1.306	1.321	.993	.316	.289	.159	-.012	.094	-.128	-.390	-1.681	-2.744	-2.744	-2.058	-.906
13.0	.528	1.199	1.599	1.616	.992	.233	.248	.112	-.060	.100	.093	.100	-1.600	-3.075	-3.075	-2.306	-1.015
12.0	.625	1.420	1.893	1.914	.991	.211	.204	.063	-.107	.100	.100	.100	-1.518	-3.404	-3.404	-2.553	-1.123
10.0	-.054	.187	.185	-.100	-.100	-.100	-.100	-.094	.100	.100	.100	.100	.100	.100	.030	.100	.100
8.0	-.100	.042	-.100	-.100	-.100	-.100	-.100	-.024	.100	.100	.100	.100	.100	.100	.100	.096	.100
6.0	.149	.517	.164	-.100	-.100	-.100	-.031	.188	.001	.100	.098	.100	.100	.100	-.141	.094	.100
4.0	.476	.916	.664	.191	-.067	-.100	-.098	.012	.032	-.008	.100	.100	.100	-1.493	-1.829	-.165	-.134
2.0	.677	1.168	.966	.641	.420	-.028	-.098	-.029	.090	.040	.070	-.387	-1.554	-3.238	-2.676	-.764	-.395
0.0	.549	.915	.754	.486	.383	.231	-.070	.130	.106	.072	-.214	-1.042	-1.709	-2.868	-1.975	-.572	-.300

KFF (IN UNITS OF KMSQ/SEC) FOR JANUARY

	SOUTH							LATITUDE (DEGREES)					NORTH				
ALT(KM)	80	70	60	50	40	30	20	10	0	10	20	30	40	50	60	70	80
50.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
47.5	.433	.440	.329	.315	.353	.560	.383	.419	.863	1.038	1.778	2.542	5.072	6.157	7.293	7.576	7.325
45.0	.394	.362	.242	.258	.308	.468	.281	.323	.695	.861	1.475	2.195	4.632	5.832	7.023	7.422	6.686
42.5	.374	.361	.199	.216	.259	.386	.249	.273	.567	.689	1.064	1.723	4.020	5.232	6.255	6.457	6.017
40.0	.353	.360	.155	.172	.209	.304	.218	.224	.439	.516	.653	1.252	3.409	4.631	5.465	5.491	5.348
37.5	.309	.311	.144	.144	.171	.272	.198	.203	.338	.363	.474	.910	3.143	4.127	4.667	4.585	4.554
35.0	.266	.263	.133	.114	.133	.240	.178	.181	.238	.210	.296	.569	2.877	3.622	3.846	3.678	3.759
34.0	.258	.256	.132	.111	.134	.227	.175	.178	.227	.195	.263	.532	2.689	3.540	3.649	3.390	3.455
33.0	.250	.250	.132	.107	.135	.214	.172	.174	.216	.180	.230	.496	2.502	3.458	3.453	3.102	3.151
32.0	.242	.243	.131	.104	.136	.201	.169	.170	.205	.165	.197	.459	2.313	3.376	3.256	2.814	2.847
31.0	.234	.237	.130	.100	.138	.189	.165	.167	.194	.150	.164	.423	2.126	3.294	3.059	2.526	2.543
30.0	.225	.230	.130	.096	.139	.176	.162	.163	.183	.135	.132	.386	1.938	3.212	2.863	2.238	2.239
29.0	.206	.208	.133	.110	.147	.180	.166	.164	.199	.154	.148	.396	1.832	3.073	2.886	2.406	2.369
28.0	.186	.186	.136	.124	.155	.184	.171	.164	.214	.173	.163	.405	1.725	2.9[illegible]	[illegible].909	2.574	2.493
27.0	.166	.164	.140	.138	.163	.187	.176	.164	.229	.191	.179	.414	1.619	2.796	2.931	2.742	2.627
26.0	.147	.141	.143	.152	.171	.191	.180	.165	.245	.210	.194	.423	1.513	2.657	2.954	2.909	2.756
25.0	.127	.119	.147	.166	.180	.195	.184	.165	.260	.228	.210	.432	1.407	2.518	2.977	3.077	2.835
24.0	.107	.097	.150	.180	.188	.199	.189	.166	.275	.247	.226	.441	1.301	2.380	3.000	3.244	3.014
23.0	.087	.074	.153	.195	.196	.203	.194	.167	.291	.266	.241	.451	1.194	2.241	3.023	3.41[illegible]	3.144
22.0	.067	.052	.157	.208	.204	.207	.198	.167	.306	.2[illegible]	256	.460	1.088	2.102	3.046	3.5[illegible]0	3 273
21.0	.047	.030	.160	.223	.212	.211	.203	.168	.321	.303	.272	.469	.982	1.963	3.069	3.748	3.402
20.0	.028	.008	.163	.237	.220	.215	.208	.168	.337	.321	.288	.478	.876	1.825	3.092	3.916	3.531
19.0	.046	.056	.208	.321	.344	.326	.270	.210	.418	.457	.505	.767	1.056	1.868	3.003	3.714	3.343
18.0	.066	.104	.254	.405	.468	.436	.333	.253	.49[illegible]	.592	.723	1.056	1.237	1.912	2.913	3.513	3.155
17.0	.085	.153	.299	.489	.592	.547	.395	.296	.579	.727	.940	1.345	1.417	1.955	2.824	3.311	2.967
16.0	.129	.229	.391	.639	.771	.670	.461	.338	.667	.865	1.206	1.740	1.705	2.094	2.797	3.152	2.810
15.0	.275	.417	.671	1.048	1.171	.845	.537	.376	.783	1.015	1.664	2.561	2.423	2.615	3.019	3.160	2.776
14.0	.421	.606	.951	1.458	1.570	1.020	.614	.414	.900	1.165	2.122	3.383	3.139	3.137	3.240	3.169	2.743
13.0	.567	.794	1.232	1.868	1.970	1.195	.690	.452	1.016	1.315	2.580	4.204	3.856	3.658	3.461	3.178	2.709
12.0	.713	.982	1.512	2.277	2.370	1.369	.767	.491	1.133	1.465	3.038	5.025	4.573	4.179	3.682	3.187	2.676
10.0	1.634	1.930	2.396	2.709	2.124	1.042	.506	.325	.848	1.210	2.555	4.694	5.794	5.901	5.061	4.151	3.493
8.0	1.715	1.990	2.264	2.254	1.496	.676	.303	.197	.550	.848	1.793	3.514	5.296	5.899	5.190	4.394	3.773
6.0	1.116	1.299	1.417	1.374	.904	.460	.230	.164	.325	.512	1.074	2.211	3.493	4.187	3.862	3.410	2.966
4.0	.702	.804	.904	.900	.610	.393	.228	.156	.233	.330	.662	1.463	2.183	2.701	2.543	2.216	1.943
2.0	.495	.511	.577	.613	.454	.339	.233	.154	.204	.242	.428	.989	1.424	1.724	1.632	1.378	1.241
0.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

V (IN UNITS OF .001 KM/SEC)   FOR   JANUARY

ALT(KM)	SOUTH 80	70	60	50	40	30	20	LATITUDE (DEGREES) 10	0	10	20	30	40	NORTH 50	60	70	80
50.0	.091	.134	.144	.133	.065	-.032	-.057	-.016	.021	.028	.034	-.057	-.143	-.136	-.132	-.128	-.104
47.5	.147	.261	.300	.328	.381	.539	.766	.986	1.103	1.095	.906	.540	.297	.236	.182	.088	-.057
45.0	.267	.451	.600	.757	.954	1.164	1.325	1.379	1.339	1.230	1.018	.709	.415	.272	.244	.240	.246
42.5	.250	.438	.622	.837	1.085	1.280	1.387	1.372	1.273	1.139	.959	.682	.306	.058	.038	.144	.268
40.0	.169	.318	.456	.640	.820	.923	.958	.910	.825	.738	.614	.442	.143	-.175	-.219	.026	.299
37.5	.119	.205	.295	.389	.443	.456	.438	.374	.335	.296	.246	.217	.101	-.237	-.363	-.022	.491
35.0	.084	.126	.179	.179	.114	.059	.022	-.016	-.011	-.010	-.004	.040	.054	-.243	-.475	-.221	.321
34.0	.069	.102	.141	.107	.008	-.064	-.102	-.118	-.096	-.079	-.050	.016	.056	-.227	-.498	-.304	.187
33.0	.037	.083	.103	.028	-.089	-.165	-.189	-.176	-.134	-.100	-.049	.039	.083	-.181	-.465	-.318	.162
32.0	.010	.054	.060	-.046	-.169	-.244	-.248	-.210	-.141	-.090	-.021	.076	.114	-.122	-.398	-.264	.254
31.0	-.001	.027	.010	-.101	-.222	-.293	-.287	-.228	-.137	-.066	.015	.111	.128	-.106	-.386	-.308	.102
30.0	-.010	.019	-.013	-.126	-.237	-.305	-.297	-.230	-.118	-.028	.060	.137	.131	-.082	-.354	-.305	.053
29.0	-.007	.026	-.009	-.125	-.229	-.296	-.293	-.224	-.103	-.002	.091	.144	.130	-.044	-.285	-.233	.145
28.0	.008	.044	.004	-.120	-.218	-.279	-.286	-.219	-.101	-.001	.092	.123	.108	-.035	-.256	-.215	.122
27.0	.033	.068	.020	-.114	-.208	-.259	-.273	-.205	-.099	-.010	.078	.093	.089	-.019	-.209	-.162	.161
26.0	.053	.083	.032	-.109	-.196	-.235	-.251	-.179	-.090	-.019	.056	.065	.075	-.013	-.182	-.136	.140
25.0	.062	.084	.033	-.100	-.177	-.202	-.217	-.139	-.063	-.015	.038	.046	.066	-.018	-.171	-.126	.108
24.0	.060	.078	.033	-.077	-.140	-.156	-.166	-.085	-.019	.006	.031	.039	.054	-.026	-.158	-.096	.144
23.0	.050	.074	.043	-.037	-.081	-.094	-.099	-.025	.030	.035	.033	.035	.030	-.056	-.165	-.096	.116
22.0	.044	.085	.069	.015	-.014	-.029	-.033	.028	.073	.067	.047	.038	.003	-.082	-.152	-.076	.097
21.0	.044	.108	.109	.065	.042	.023	.014	.058	.106	.105	.074	.046	-.023	-.100	-.122	-.041	.089
20.0	.046	.131	.142	.096	.075	.047	.024	.060	.129	.151	.115	.061	-.038	-.108	-.093	-.017	.057
19.0	.042	.135	.153	.102	.087	.049	-.006	.034	.152	.212	.165	.080	-.038	-.105	-.063	.013	.059
18.0	.033	.116	.135	.087	.100	.036	-.090	-.013	.235	.344	.214	.083	-.026	-.081	-.032	.031	.059
17.0	.008	.074	.101	.085	.113	.024	-.092	.039	.462	.681	.363	.047	-.088	-.135	-.077	-.011	-.005
16.0	-.034	.017	.068	.109	.106	.027	.053	.243	.830	1.223	.650	-.020	-.263	-.320	-.222	-.121	-.184
15.0	-.064	-.029	.045	.134	.079	.038	.224	.499	1.243	1.769	.960	-.054	-.427	-.492	-.320	-.176	-.342
14.0	-.075	-.054	.023	.133	.049	.036	.291	.677	1.549	2.065	1.144	-.020	-.463	-.511	-.255	-.076	-.276
13.0	-.077	-.062	-.000	.104	.038	.011	.218	.686	1.605	1.948	1.075	.009	-.419	-.427	-.135	.042	-.134
12.0	-.082	-.063	-.022	.075	.046	-.032	.112	.571	1.391	1.531	.820	-.027	-.392	-.370	-.114	.045	-.042
10.0	-.075	-.045	-.033	.062	.056	-.072	.004	.296	.680	.687	.360	-.098	-.329	-.340	-.178	-.021	.028
8.0	-.042	-.020	-.017	.045	.044	-.041	-.077	.027	.075	.161	.121	-.047	-.160	-.226	-.115	-.003	-.030
6.0	.001	-.007	.001	-.004	.005	-.003	-.125	-.204	-.289	-.132	.004	.032	.009	-.032	.012	.032	-.034
4.0	.032	.000	.003	-.042	-.029	.013	-.072	-.268	-.406	-.432	-.174	.062	.146	.156	.094	.034	.042
2.0	.032	.006	-.020	-.065	-.052	.026	.035	-.162	-.548	-.789	-.481	-.000	.221	.267	.129	.008	.034
0.0	.008	.003	-.056	-.087	-.066	.082	.369	.573	.236	-.206	-.247	-.036	.134	.206	.103	.004	-.052

W (IN UNITS OF .000001 KM/SEC)   FOR   JANUARY

				SOUTH				LATITUDE (DEGREES)						NORTH			
ALT(KM)	80	70	60	50	40	30	20	10	0	10	20	30	40	50	60	70	80
50.0	5.120	3.150	2.310	2.390	2.740	2.730	2.160	1.310	.435	-.945	-1.540	-2.390	-3.970	-4.290	-5.610	-7.170	-7.730
47.5	4.035	2.485	1.640	1.680	2.075	2.415	2.220	1.595	.557	-.799	-1.775	-2.655	-3.220	-3.085	-4.195	-5.220	-5.740
45.0	3.720	2.390	1.610	1.600	1.900	2.210	1.990	1.330	.385	-.882	-1.900	-2.640	-2.680	-2.450	-3.200	-3.960	-4.340
42.5	3.670	2.520	1.905	1.890	2.085	2.100	1.685	.908	.036	-1.012	-1.950	-2.705	-2.640	-2.030	-2.325	-2.875	-3.260
40.0	3.370	2.470	2.050	2.070	2.130	1.860	1.340	.559	-.214	-1.010	-1.870	-2.640	-2.680	-1.670	-1.330	-1.700	-2.310
37.5	2.865	2.185	1.890	1.935	1.810	1.440	.946	.269	-.265	-.859	-1.560	-2.190	-2.420	-1.570	-.392	-.453	-1.755
35.0	2.350	1.790	1.580	1.520	1.290	.982	.599	.083	-.199	-.648	-1.120	-1.520	-1.940	-1.680	.154	.710	-1.290
34.0	2.150	1.630	1.430	1.300	1.050	.805	.486	.055	-.152	-.551	-.932	-1.260	-1.730	-1.710	.232	1.070	-1.030
33.0	1.940	1.480	1.260	1.060	.816	.645	.398	.055	-.099	-.453	-.746	-1.020	-1.530	-1.730	.248	1.350	-.748
32.0	1.730	1.330	1.080	.810	.598	.505	.343	.078	-.037	-.354	-.573	-.809	-1.360	-1.740	.223	1.550	-.466
31.0	1.520	1.180	.892	.574	.406	.386	.314	.118	.035	-.254	-.416	-.636	-1.230	-1.730	.170	1.680	-.215
30.0	1.320	1.030	.709	.365	.242	.283	.296	.167	.116	-.156	-.281	-.504	-1.130	-1.710	.102	1.760	-.013
29.0	1.140	.900	.543	.187	.107	.193	.281	.217	.201	-.062	-.172	-.415	-1.050	-1.660	.028	1.790	.139
28.0	.996	.791	.396	.034	.000	.113	.261	.261	.276	.022	-.084	-.360	-.965	-1.590	-.045	1.780	.236
27.0	.899	.702	.268	-.099	-.083	.048	.233	.299	.332	[illegible]	-.015	-.327	-.867	-1.500	-.108	[illegible]	.286
26.0	.844	.628	.155	-.218	-.145	-.000	.203	.332	.360	[illegible]	.040	-.301	-.758	-1.400	-.156	[illegible]	.295
25.0	.812	.563	.060	-.317	-.188	-.030	.174	.362	.361	.168	.077	-.271	-.649	-1.310	-.187	1.600	.275
24.0	.785	.502	-.015	-.386	-.213	-.046	.152	.390	.345	[illegible]	.094	-.235	-.554	-1.230	-.199	1.530	.242
23.0	.753	.451	-.062	-.417	-.219	-.052	.139	.409	.317	.147	.089	-.200	-.486	1.140	-.191	1.470	.206
22.0	.718	.421	-.081	-.409	-.210	-.053	.131	.412	.283	.109	.066	-.175	[illegible]	-1.050	-.158	1.410	.172
21.0	.695	.421	-.073	-.377	-.190	-.054	.124	.399	.252	.070	.031	-.168	-.439	-.938	-.098	1.330	.143
20.0	.688	.451	-.048	-.340	-.165	-.061	.111	.379	.241	.039	-.013	-.188	-.449	-.812	-.021	1.230	.116
19.0	.692	.495	-.018	-.309	-.143	-.078	.088	.371	.262	.026	-.070	-.232	-.467	-.686	.062	1.110	.092
18.0	.685	.531	.009	-.284	-.117	-.114	.039	.396	.330	.028	-.153	[illegible]	-.489	-.572	.144	.991	.074
17.0	.658	.539	.030	-.249	-.078	-.211	-.047	.530	.523	-.019	-.352	-.335	-.482	-.479	.191	.862	.074
16.0	.578	.525	.067	-.189	-.062	-.272	-.024	.713	.864	-.052	-.842	-.536	-.441	-.374	.297	.800	.105
15.0	.453	.497	.126	-.111	-.089	-.238	.159	.941	1.350	-.060	-1.670	-.971	-.380	-.229	.504	.795	.141
14.0	.315	.459	.193	-.035	-.148	-.121	.448	1.240	1.910	-.095	-2.670	-1.560	-.330	-.053	.785	.776	.146
13.0	.187	.413	.242	.029	-.203	-.006	.734	1.630	2.440	-.242	-3.560	-2.130	-.305	.134	1.040	.691	.108
12.0	.076	.364	.262	.082	-.242	.024	.935	2.040	2.830	-.531	-4.110	-2.530	-.295	.315	1.200	.574	.059
10.0	-.115	.286	.251	.192	-.287	-.107	1.200	2.480	3.060	-1.090	-4.300	-2.870	-.250	.588	1.300	.561	.076
8.0	-.207	.251	.229	.289	-.337	-.237	1.200	2.330	2.610	-.999	-3.840	-2.750	-.243	.586	1.420	.652	.137
6.0	-.207	.211	.198	.295	-.305	-.315	.829	1.960	2.060	-.507	-3.140	-2.310	-.278	.432	1.390	.499	.105
4.0	-.136	.140	.168	.174	-.198	-.302	.357	1.360	1.640	.025	-2.320	-1.790	-.263	.316	1.070	.307	.059
2.0	-.050	.061	.111	.069	-.096	-.201	.075	.643	.973	.263	-1.230	-1.010	-.182	.148	.533	.162	.025
0.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

T (IN UNITS OF 100. DEGREES KELVIN) FOR APRIL

	SOUTH							LATITUDE (DEGREES)						NORTH			
ALT(KM)	80	70	60	50	40	30	20	10	0	10	20	30	40	50	60	70	80
50.0	2.438	2.657	2.676	2.696	2.715	2.724	2.723	2.721	2.715	2.6[illegible]	2.672	2.[illegible]61	2.662	2.673	2.673	2.7[illegible]9	2.754
47.5	2.573	2.598	2.627	2.655	2.679	2.697	2.703	2.704	2.700	2.699	2.682	2.675	2.665	2.655	2.649	2.679	2.719
45.0	2.509	2.535	2.571	2.604	2.633	2.654	2.664	2.668	2.667	2.670	2.659	2.651	2.636	2.614	2.610	2.637	2.673
42.5	2.446	2.474	2.511	2.544	2.573	2.598	2.612	2.619	2.620	2.622	2.613	2.602	2.582	2.561	2.560	2.586	2.618
40.0	2.381	2.410	2.449	2.484	2.515	2.540	2.556	2.564	2.567	2.567	2.559	2.545	2.526	2.504	2.505	2.530	2.560
37.5	2.320	2.348	2.386	2.423	2.455	2.482	2.498	2.508	2.510	2.510	2.502	2.488	2.469	2.447	2.448	2.473	2.500
35.0	2.263	2.288	2.324	2.362	2.396	2.425	2.442	2.451	2.452	2.450	2.442	2.430	2.411	2.391	2.393	2.415	2.440
34.0	2.243	2.266	2.301	2.338	2.372	2.401	2.420	2.427	2.429	2.425	2.418	2.405	2.389	2.371	2.372	2.392	2.419
33.0	2.223	2.246	2.279	2.314	2.349	2.378	2.396	2.403	2.405	2.401	2.394	2.382	2.367	2.351	2.351	2.371	2.397
32.0	2.205	2.227	2.259	2.292	2.325	2.355	2.373	2.379	2.382	2.377	2.370	2.359	2.344	2.332	2.331	2.348	2.373
31.0	2.188	2.210	2.240	2.271	2.302	2.332	2.351	2.356	2.358	2.352	2.348	2.335	2.323	2.314	2.313	2.328	2.352
30.0	2.172	2.194	2.223	2.250	2.280	2.309	2.327	2.332	2.334	2.329	2.324	2.312	2.303	2.296	2.296	2.309	2.332
29.0	2.157	2.179	2.208	2.232	2.258	2.285	2.304	2.306	2.309	2.306	2.301	2.290	2.285	2.280	2.281	2.292	2.314
28.0	2.144	2.167	2.195	2.216	2.237	2.263	2.279	2.282	2.285	2.282	2.278	2.269	2.267	2.267	2.268	2.277	2.298
27.0	2.132	2.157	2.185	2.202	2.217	2.239	2.256	2.258	2.259	2.257	2.255	2.248	2.251	2.254	2.256	2.265	2.286
26.0	2.121	2.148	2.176	2.190	2.200	2.217	2.231	2.233	2.233	2.231	2.231	2.227	2.235	2.241	2.243	2.254	2.276
25.0	2.112	2.141	2.168	2.180	2.185	2.195	2.205	2.206	2.206	2.204	2.206	2.206	2.221	2.230	2.232	2.245	2.268
24.0	2.104	2.134	2.163	2.173	2.173	2.174	2.178	2.178	2.177	2.177	2.181	2.185	2.207	2.220	2.225	2.237	2.260
23.0	2.099	2.130	2.159	2.169	2.163	2.154	2.151	2.149	2.149	2.150	2.154	2.165	2.195	2.212	2.219	2.232	2.254
22.0	2.097	2.128	2.158	2.166	2.155	2.135	2.123	2.119	2.117	2.119	2.126	2.147	2.185	2.205	2.215	2.229	2.249
21.0	2.100	2.131	2.159	2.166	2.150	2.117	2.095	2.086	2.082	2.085	2.097	2.130	2.177	2.200	2.211	2.227	2.246
20.0	2.107	2.136	2.163	2.168	2.145	2.100	2.064	2.047	2.044	2.049	2.067	2.111	2.168	2.196	2.208	2.226	2.245
19.0	2.117	2.145	2.170	2.172	2.141	2.085	2.035	2.007	2.002	2.012	2.037	2.092	2.158	2.193	2.208	2.227	2.244
18.0	2.131	2.158	2.181	2.177	2.139	2.073	2.011	1.972	1.962	1.979	2.012	2.074	2.147	2.189	2.207	2.228	2.245
17.0	2.148	2.174	2.191	2.180	2.135	2.063	1.998	1.954	1.943	1.964	1.998	2.061	2.137	2.185	2.206	2.227	2.245
16.0	2.167	2.190	2.201	2.183	2.132	2.060	2.004	1.973	1.968	1.985	2.012	2.062	2.132	2.182	2.207	2.227	2.243
15.0	2.183	2.204	2.209	2.184	2.134	2.076	2.042	2.032	2.031	2.040	2.056	2.086	2.137	2.180	2.206	2.225	2.240
14.0	2.195	2.212	2.211	2.183	2.142	2.112	2.108	2.109	2.110	2.114	2.120	2.127	2.150	2.180	2.204	2.222	2.235
13.0	2.200	2.214	2.209	2.182	2.161	2.164	2.182	2.188	2.189	2.192	2.191	2.179	2.174	2.183	2.202	2.217	2.230
12.0	2.195	2.211	2.205	2.186	2.193	2.223	2.252	2.260	2.263	2.266	2.262	2.239	2.207	2.194	2.201	2.213	2.226
10.0	2.179	2.194	2.211	2.249	2.303	2.351	2.383	2.396	2.402	2.403	2.396	2.366	2.310	2.250	2.217	2.217	2.226
8.0	2.202	2.232	2.291	2.373	2.438	2.484	2.518	2.532	2.536	2.534	2.523	2.490	2.430	2.351	2.285	2.255	2.249
6.0	2.296	2.347	2.420	2.499	2.563	2.612	2.646	2.660	2.664	2.660	2.646	2.613	2.550	2.473	2.406	2.362	2.337
4.0	2.406	2.459	2.533	2.610	2.678	2.730	2.764	2.777	2.781	2.777	2.760	2.722	2.661	2.589	2.524	2.475	2.445
2.0	2.502	2.554	2.627	2.705	2.774	2.828	2.864	2.878	2.883	2.880	2.859	2.816	2.757	2.693	2.630	2.577	2.542
0.0	2.577	2.630	2.701	2.779	2.850	2.911	2.952	2.965	2.973	2.971	2.946	2.897	2.838	2.780	2.711	2.641	2.587

KZZ (IN UNITS OF .00001 KMSQ/SEC) FOR APRIL

	SOUTH						LATITUDE (DEGREES)						NORTH			
ALT(KM)	80	70	60	50	40	30	20	10	0	10	20	30	40	50	60	70	80
50.0	1.966	1.966	1.966	5.081	2.168	.440	.156	.177	.256	.275	.206	.906	3.085	2.281	3.288	3.288	3.288
47.5	1.475	1.475	1.475	3.812	1.626	.330	.117	.133	.192	.207	.155	.680	2.314	1.711	2.467	2.467	2.467
45.0	1.107	1.107	1.107	2.860	1.220	.248	.088	.100	.144	.155	.116	.510	1.736	1.284	1.851	1.851	1.851
42.5	.830	.830	.830	2.146	.915	.186	.066	.075	.108	.116	.087	.383	1.303	.963	1.388	1.388	1.388
40.0	.623	.623	.623	1.610	.687	.139	.049	.056	.081	.087	.065	.287	.977	.723	1.042	1.042	1.042
37.5	.467	.467	.467	1.208	.515	.105	.037	.042	.061	.065	.049	.215	.733	.542	.782	.782	.782
35.0	.351	.351	.351	.906	.387	.078	.028	.032	.046	.049	.037	.162	.550	.407	.586	.586	.586
34.0	.312	.312	.312	.808	.345	.070	.025	.028	.041	.044	.033	.144	.490	.363	.523	.523	.523
33.0	.279	.279	.279	.720	.307	.062	.022	.025	.036	.039	.029	.128	.437	.323	.466	.466	.466
32.0	.248	.248	.248	.642	.274	.056	.020	.022	.032	.035	.026	.114	.390	.288	.415	.415	.415
31.0	.221	.221	.221	.572	.244	.050	.018	.020	.029	.031	.023	.102	.347	.257	.370	.370	.370
30.0	.197	.197	.197	.510	.218	.044	.016	.018	.026	.028	.021	.091	.310	.229	.330	.330	.330
29.0	.176	.176	.176	.455	.194	.039	.014	.016	.023	.025	.018	.081	.276	.204	.294	.294	.294
28.0	.157	.157	.157	.405	.173	.035	.012	.014	.020	.022	.016	.072	.246	.182	.262	.262	.262
27.0	.140	.140	.140	.361	.154	.031	.011	.013	.018	.020	.015	.064	.219	.162	.234	.234	.234
26.0	.125	.125	.125	.322	.137	.028	.010	.011	.016	.017	.013	.057	.195	.145	.208	.208	.208
25.0	.111	.111	.111	.287	.122	.025	.009	.010	.014	.016	.012	.051	.174	.129	.186	.186	.186
24.0	.099	.099	.099	.256	.109	.022	.008	.009	.013	.014	.010	.046	.155	.115	.166	.166	.166
23.0	.088	.088	.088	.228	.097	.020	.007	.008	.011	.012	.009	.041	.138	.102	.148	.148	.148
22.0	.079	.079	.079	.203	.087	.018	.006	.007	.010	.011	.008	.036	.123	.091	.132	.132	.132
21.0	.070	.070	.070	.181	.077	.016	.006	.006	.009	.010	.007	.032	.110	.081	.117	.117	.117
20.0	.063	.063	.063	.162	.069	.014	.005	.006	.008	.009	.007	.029	.098	.073	.105	.105	.105
19.0	.080	.080	.080	.157	.095	.034	.014	.009	.010	.013	.022	.069	.117	.083	.097	.097	.097
18.0	.098	.098	.098	.152	.122	.054	.023	.012	.012	.017	.038	.110	.137	.094	.089	.089	.089
17.0	.115	.115	.115	.147	.148	.075	.031	.015	.014	.021	.054	.150	.156	.105	.081	.081	.081
16.0	.129	.129	.129	.146	.172	.092	.040	.018	.018	.025	.067	.179	.172	.117	.080	.080	.080
15.0	.127	.127	.127	.161	.160	.088	.050	.019	.028	.031	.065	.157	.172	.133	.102	.102	.102
14.0	.125	.125	.125	.175	.147	.084	.060	.020	.038	.036	.063	.135	.172	.150	.125	.125	.125
13.0	.123	.123	.123	.189	.135	.080	.070	.023	.049	.045	.061	.112	.173	.167	.147	.147	.147
12.0	.058	.060	.121	.203	.122	.076	.089	.032	.063	.058	.078	.137	.173	.184	.168	.166	.165
10.0	.080	.089	.129	.195	.340	.124	.142	.061	.105	.100	.128	.204	.289	.136	.104	.103	.103
8.0	.105	.114	.153	.329	.462	.203	.227	.116	.177	.172	.209	.304	.403	.162	.119	.118	.118
6.0	.113	.127	.205	.479	.614	.334	.364	.220	.299	.295	.342	.454	.560	.284	.170	.091	.086
4.0	.219	.288	.397	.700	.822	.550	.582	.418	.508	.507	.561	.677	.779	.497	.344	.230	.204
2.0	.573	.657	.772	1.023	1.107	.908	.934	.792	.870	.872	.917	1.008	1.081	.865	.709	.586	.551
0.0	1.500	1.500	1.500	1.500	1.500	1.500	1.500	1.500	1.500	1.500	1.500	1.500	1.500	1.500	1.500	1.500	1.500

KFZ (IN UNITS OF .001 KMSQ/SEC) FOR APRIL

ALT(KM)	SOUTH 80	70	60	50	40	30	20	LATITUDE (DEGREES) 10	0	10	20	30	40	NORTH 50	60	70	80
50.0	.358	.814	1.085	1.078	1.294	.324	.021	-.005	-.036	-.093	-.065	-.355	-.925	-.825	-.825	-.619	-.272
47.5	.425	.966	1.288	1.280	1.294	.324	.021	-.005	-.036	-.097	-.065	-.355	-.925	-.825	-.825	-.619	-.272
45.0	.492	1.118	1.491	1.482	1.473	.356	.021	-.006	-.036	-.101	-.066	-.372	-1.010	-.928	-.928	-.696	-.306
42.5	.497	1.129	1.506	1.497	1.409	.328	.017	-.005	-.033	-.094	-.058	-.329	-1.031	-.965	-.965	-.724	-.318
40.0	.502	1.140	1.520	1.511	1.346	.301	.013	-.005	-.031	-.087	-.051	-.287	-1.052	-1.001	-1.001	-.751	-.330
37.5	.467	1.060	1.414	1.405	1.311	.236	.011	-.004	-.027	-.080	-.048	-.256	-1.114	-1.021	-1.021	-.766	-.337
35.0	.431	.981	1.307	1.298	1.275	.171	.008	-.003	-.023	-.073	-.044	-.224	-1.176	-1.041	-1.041	-.781	-.344
34.0	.432	.982	1.309	1.300	1.226	.157	.007	-.003	-.023	-.074	-.044	-.228	-1.145	-1.054	-1.054	-.790	-.348
33.0	.433	.983	1.311	1.301	1.177	.142	.006	-.003	-.022	-.075	-.044	-.231	-1.114	-1.067	-1.067	-.800	-.352
32.0	.433	.985	1.313	1.303	1.128	.128	.006	-.003	-.022	-.077	-.044	-.235	-1.083	-1.079	-1.079	-.810	-.356
31.0	.434	.986	1.315	1.305	1.079	.114	.005	-.003	-.022	-.078	-.044	-.238	-1.052	-1.092	-1.092	-.819	-.360
30.0	.434	.987	1.316	1.307	1.029	.099	.004	-.003	-.022	-.079	-.044	-.241	-1.020	-1.105	-1.105	-.829	-.365
29.0	.433	.985	1.313	1.303	.987	.107	.005	-.003	-.025	-.081	-.046	-.251	-.997	-1.072	-1.072	-.804	-.354
28.0	.432	.982	1.309	1.300	.944	.115	.006	-.003	-.027	-.084	-.047	-.260	-.973	-1.039	-1.039	-.779	-.343
27.0	.431	.979	1.305	1.296	.902	.123	.007	-.003	-.030	-.086	-.049	-.269	-.949	-1.005	-1.005	-.754	-.332
26.0	.429	.976	1.301	1.293	.860	.131	.008	-.004	-.033	-.088	-.050	-.278	-.925	-.972	-.972	-.729	-.321
25.0	.428	.973	1.298	1.289	.817	.139	.009	-.004	-.035	-.091	-.052	-.287	-.901	-.939	-.939	-.704	-.310
24.0	.425	.966	1.289	1.280	.775	.147	.009	-.004	-.038	-.093	-.053	-.296	-.878	-.932	-.932	-.699	-.307
23.0	.422	.960	1.280	1.272	.732	.155	.010	-.004	-.041	-.095	-.055	-.305	-.854	-.924	-.924	-.693	-.305
22.0	.419	.953	1.271	1.263	.690	.163	.011	-.004	-.043	-.097	-.056	-.314	-.830	-.917	-.917	-.688	-.303
21.0	.416	.946	1.262	1.254	.647	.171	.012	-.004	-.046	-.100	-.058	-.323	-.806	-.910	-.910	-.683	-.300
20.0	.413	.940	1.253	1.246	.605	.179	.013	-.004	-.049	-.102	-.059	-.332	-.783	-.903	-.903	-.677	-.298
19.0	.426	.969	1.292	1.284	.828	.393	.110	.037	-.062	-.144	-.218	-.693	-.985	-.971	-.971	-.728	-.320
18.0	.439	.999	1.332	1.323	1.050	.607	.208	.079	-.075	-.186	-.376	-1.053	-1.188	-1.040	-1.040	-.780	-.343
17.0	.452	1.028	1.371	1.361	1.273	.821	.305	.120	-.088	-.228	-.534	-1.413	-1.391	-1.108	-1.108	-.831	-.366
16.0	.472	1.072	1.429	1.418	1.438	.942	.373	.142	-.093	-.241	-.621	-1.583	-1.581	-1.205	-1.205	-.903	-.398
15.0	.544	1.236	1.648	1.636	1.373	.666	.321	.083	-.052	-.136	-.425	-.948	-1.720	-1.544	-1.544	-1.158	-.509
14.0	.618	1.405	1.874	1.859	1.309	.410	.270	.017	-.023	-.044	-.229	-.363	-1.859	-1.891	-1.891	-1.419	-.624
13.0	.693	1.575	2.100	2.083	1.244	.214	.213	-.053	.007	.010	-.038	.100	-1.999	-2.247	-2.247	-1.685	-.742
12.0	.768	1.746	2.328	2.307	1.179	.135	.156	-.100	.016	.040	.083	.100	-2.138	-2.61[illegible]	-2.612	-1.959	-.862
10.0	-.100	-.100	-.100	-.100	-.100	-.100	-.100	-.088	.009	.100	.100	.100	.100	.099	-.340	-.069	.060
8.0	-.100	-.100	-.100	-.100	-.100	-.100	-.100	-.056	-.005	.100	.100	.100	.100	.100	.100	.066	.100
6.0	.156	-.084	-.059	-.100	-.100	-.100	-.100	-.056	-.099	.078	.100	.100	.100	.100	.100	.015	-.055
4.0	.462	.705	1.372	.564	-.089	-.100	-.100	-.090	-.006	.045	.100	.100	.100	-.963	-1.116	-.499	-.462
2.0	.686	1.117	2.168	1.931	.785	.120	-.098	-.079	.050	.100	.100	-.381	-1.213	-2.002	-1.943	-.957	-.563
0.0	.513	.829	1.688	1.694	.903	.490	-.031	-.094	.021	.0[illegible]	-.052	-.766	-1.190	-1.716	-1.575	-.7[illegible]	-.412

KFF (IN UNITS OF KMSQ/SEC) FOR APRIL

	SOUTH							LATITUDE (DEGREES)						NORTH			
ALT(KM)	80	70	60	50	40	30	20	10	0	10	20	30	40	50	60	70	80
50.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
47.5	4.974	4.955	3.962	2.781	3.243	1.746	.982	.542	.757	.880	1.071	1.320	2.049	2.992	3.417	3.191	3.807
45.0	4.788	4.712	3.625	2.666	3.038	1.562	.813	.406	.609	.747	.861	1.114	1.821	2.765	3.175	[illegible]	3.088
42.5	4.607	4.504	3.036	2.347	2.559	1.274	.587	.329	.499	.613	.682	.881	1.623	2.504	2.891	2.232	2.481
40.0	4.425	4.296	2.448	2.029	2.081	.985	.362	.251	.388	.481	.503	.648	1.423	2.242	2.607	1.718	1.873
37.5	3.870	3.656	1.998	1.704	1.831	.718	.266	.190	.312	.400	.426	.534	1.347	2.054	2.282	1.435	1.558
35.0	3.315	3.015	1.549	1.378	1.580	.451	.171	.128	.236	.319	.350	.420	1.270	1.865	1.958	1.152	1.243
34.0	3.032	2.769	1.445	1.333	1.476	.405	.150	.119	.227	.312	.338	.412	1.201	1.823	1.874	1.082	1.171
33.0	2.748	2.524	1.341	1.288	1.373	.358	.129	.110	.218	.306	.327	.405	1.132	1.781	1.789	1.012	1.098
32.0	2.464	2.278	1.236	1.244	1.269	.312	.108	.100	.210	.300	.315	.397	1.062	1.738	1.705	.942	1.026
31.0	2.181	2.032	1.132	1.198	1.166	.265	.087	.091	.201	.294	.303	.390	.993	1.695	1.620	.873	.953
30.0	1.898	1.787	1.028	1.153	1.062	.219	.067	.082	.193	.287	.291	.382	.924	1.653	1.536	.802	.881
29.0	1.836	1.737	1.052	1.123	1.003	.227	.077	.094	.205	.286	.292	.383	.886	1.574	1.514	.914	.932
28.0	1.775	1.688	1.077	1.093	.943	.234	.088	.105	.218	.286	.292	.384	.848	1.495	1.493	1.025	1.084
27.0	1.713	1.638	1.101	1.062	.884	.242	.099	.117	.231	.284	.292	.385	.810	1.416	1.471	1.135	1.186
26.0	1.652	1.588	1.126	1.032	.824	.249	.109	.129	.244	.284	.293	.386	.772	1.337	1.450	1.247	1.288
25.0	1.591	1.538	1.150	1.002	.764	.256	.120	.141	.256	.283	.293	.388	.734	1.258	1.428	1.358	1.390
24.0	1.529	1.488	1.175	.971	.705	.264	.130	.153	.269	.282	.294	.389	.696	1.179	1.407	1.469	1.492
23.0	1.468	1.439	1.199	.941	.645	.271	.141	.165	.281	.281	.294	.390	.659	1.101	1.386	1.580	1.594
22.0	1.407	1.389	1.223	.911	.586	.279	.152	.177	.294	.280	.294	.391	.621	1.022	1.364	1.691	1.695
21.0	1.346	1.339	1.248	.881	.526	.286	.163	.189	.307	.279	.294	.392	.583	.943	1.343	1.802	1.797
20.0	1.284	1.289	1.272	.850	.467	.294	.174	.200	.319	.278	.294	.393	.545	.864	1.322	1.913	1.899
19.0	1.253	1.264	1.261	.946	.625	.440	.273	.255	.371	.373	.448	.624	.724	.958	1.379	1.879	1.785
18.0	1.222	1.239	1.249	1.042	.784	.586	.371	.310	.423	.468	.603	.853	.902	1.052	1.436	1.845	1.672
17.0	1.191	1.214	1.238	1.138	.943	.733	.470	.364	.475	.563	.757	1.084	1.081	1.147	1.494	1.812	1.558
16.0	1.193	1.228	1.295	1.325	1.182	.931	.590	.423	.528	.659	.947	1.387	1.345	1.316	1.588	1.797	1.468
15.0	1.332	1.400	1.627	1.830	1.742	1.337	.796	.495	.587	.756	1.283	1.986	1.951	1.788	1.827	1.861	1.477
14.0	1.471	1.573	1.959	2.435	2.303	1.742	1.002	.566	.645	.854	1.619	2.585	2.556	2.259	2.067	1.925	1.484
13.0	1.611	1.745	2.292	2.990	2.864	2.148	1.209	.639	.704	.952	1.955	3.184	3.162	2.730	2.307	1.990	1.493
12.0	1.750	1.917	2.624	3.546	3.424	2.554	1.415	.711	.763	1.049	2.291	3.783	3.767	3.202	2.546	2.054	1.501
10.0	2.669	2.780	3.628	4.362	3.658	2.233	1.038	.541	.567	.853	1.852	3.430	4.598	4.774	3.988	3.102	2.299
8.0	2.854	2.898	3.513	3.932	3.030	1.614	.725	.363	.386	.602	1.264	2.503	4.006	4.687	4.154	3.405	2.576
6.0	2.168	2.116	2.406	2.632	1.919	1.032	.465	.246	.254	.372	.762	1.591	2.601	3.197	2.979	2.603	1.994
4.0	1.378	1.328	1.554	1.667	1.201	.724	.347	.207	.190	.263	.500	1.110	1.679	2.055	1.919	1.633	1.280
2.0	.849	.837	1.042	1.063	.792	.527	.278	.182	.159	.205	.361	.779	1.128	1.315	1.187	.979	.841
0.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

V (IN UNITS OF .001 KM/SEC) FOR APRIL

ALT(KM)	SOUTH 80	70	60	50	40	30	20	LATITUDE (DEGREES) 10	0	10	20	30	40	NORTH 50	60	70	80
50.0	.091	.134	.144	.133	.065	-.032	-.057	-.016	.021	.028	.034	-.057	-.143	-.136	-.132	-.128	-.104
47.5	.167	.252	.446	.695	.801	.755	.639	.472	.257	.061	-.111	-.266	-.313	-.209	-.029	.024	-.107
45.0	.164	.207	.355	.522	.603	.567	.503	.402	.256	.101	-.017	-.122	-.159	-.009	.008	-.006	-.149
42.5	.180	.256	.340	.382	.342	.302	.280	.249	.177	.096	.056	.023	-.010	-.014	-.017	-.042	-.098
40.0	.190	.319	.371	.332	.227	.189	.182	.161	.105	.055	.032	.034	-.004	-.092	-.139	-.093	-.024
37.5	.191	.354	.417	.322	.217	.187	.175	.130	.055	-.005	-.042	-.046	-.091	-.236	-.295	-.174	.014
35.0	.170	.360	.446	.345	.229	.179	.151	.095	.030	-.032	-.067	-.078	-.128	-.285	-.378	-.247	-.012
34.0	.164	.338	.437	.350	.228	.163	.127	.079	.034	-.018	-.049	-.052	-.097	-.248	-.358	-.242	.033
33.0	.169	.325	.403	.345	.223	.142	.102	.066	.042	.005	-.022	-.014	-.047	-.192	-.323	-.232	.028
32.0	.158	.300	.357	.321	.213	.126	.080	.054	.052	.031	.011	.029	.008	-.131	-.270	-.208	.021
31.0	.135	.270	.320	.300	.209	.124	.075	.055	.073	.066	.057	.077	.059	-.072	-.207	-.155	.057
30.0	.101	.232	.283	.273	.198	.125	.075	.060	.090	.095	.099	.108	.083	-.038	-.159	-.112	.066
29.0	.081	.199	.256	.247	.186	.120	.076	.070	.108	.122	.139	.132	.095	-.013	-.110	-.064	.082
28.0	.063	.177	.238	.223	.169	.104	.072	.081	.121	.139	.167	.147	.103	.010	-.065	-.021	.098
27.0	.052	.165	.221	.197	.145	.074	.055	.080	.117	.137	.172	.146	.101	.022	-.041	.005	.112
26.0	.055	.166	.212	.179	.121	.042	.031	.070	.102	.122	.155	.134	.097	.034	-.021	.032	.158
25.0	.062	.165	.198	.158	.093	.013	-.001	.043	.072	.091	.114	.101	.080	.031	-.018	.042	.183
24.0	.072	.166	.186	.138	.070	.000	-.026	.012	.038	.055	.061	.056	.049	.010	-.033	.033	.172
23.0	.074	.166	.178	.121	.058	.004	-.035	-.014	.013	.029	.016	.013	.021	-.012	-.043	.028	.159
22.0	.065	.156	.163	.100	.050	.012	-.037	-.030	.000	.019	-.009	-.019	-.004	-.028	-.045	.028	.142
21.0	.052	.140	.142	.075	.044	.015	-.037	-.039	.002	.028	-.008	-.032	-.016	-.033	-.035	.035	.127
20.0	.026	.119	.119	.051	.045	.023	-.037	-.046	.014	.053	.009	-.035	-.024	-.034	-.020	.041	.098
19.0	-.008	.104	.110	.050	.075	.051	-.046	-.088	.035	.104	.047	-.026	-.031	-.030	.008	.073	.130
18.0	-.047	.090	.110	.065	.108	.048	-.144	-.279	.049	.234	.131	-.021	-.077	-.095	-.062	-.036	-.109
17.0	-.067	.055	.086	.063	.094	.007	-.338	-.486	.078	.379	.226	.021	-.034	-.021	.047	.108	.168
16.0	-.055	-.004	.029	.035	.035	-.024	-.532	-.530	.146	.454	.281	.057	.071	.194	.355	.548	1.050
15.0	-.027	-.057	-.026	.002	-.028	-.031	-.652	-.451	.226	.472	.214	-.086	-.036	.146	.321	.494	.955
14.0	-.008	-.077	-.046	-.007	-.052	-.015	-.663	-.348	.311	.478	.170	-.167	-.117	.079	.267	.434	.831
13.0	-.008	-.058	-.025	.021	-.027	.003	-.603	-.322	.356	.486	.177	-.150	-.152	.001	.195	.361	.669
12.0	-.016	-.032	-.002	.054	.004	-.003	-.516	-.316	.333	.461	.111	-.229	-.325	-.266	-.156	-.154	-.369
10.0	-.023	-.019	.005	.079	.030	-.033	-.301	-.174	.215	.250	.017	-.181	-.319	-.302	-.233	-.289	-.639
8.0	-.033	-.026	.004	.065	.033	-.046	-.119	-.065	.045	.040	-.004	-.023	-.127	-.099	-.004	.024	-.023
6.0	-.030	-.017	.001	.011	.013	-.033	-.029	-.048	-.102	-.047	-.007	.019	-.057	-.036	.017	.030	.021
4.0	-.001	-.002	-.009	-.040	-.016	.000	.084	.034	-.142	-.115	-.018	.056	.069	.062	.032	.024	.061
2.0	.026	.000	-.035	-.072	-.042	.026	.340	.250	-.121	-.252	-.081	.091	.193	.136	.033	-.003	.033
0.0	.008	.003	-.056	-.087	-.066	.082	.369	.573	.236	-.206	-.247	-.036	.134	.206	.103	.004	-.052

W (IN UNITS OF .000001 KM/SEC) FOR APRIL

	SOUTH						LATITUDE (DEGREES)						NORTH			
ALT(KM)	30	70	60	50	40	30	20	10	0	10	20	30	40	50	60	70	80
50.0	-.455	-.116	.106	-.090	-.341	-.431	-.538	-.613	-.327	[illegible]	.429	.869	.918	.794	.368	-.541	-1.390
47.5	.350	.627	.919	.694	.035	-.337	-.640	-.816	-.705	.293	.010	.451	.819	1.011	.651	-.374	-1.150
45.0	.721	.886	1.410	1.230	.387	-.251	-.603	-.902	-.875	-.564	-.289	.140	.712	1.070	.719	-.400	-.930
42.5	.998	.979	1.475	1.235	.433	-.170	-.463	-.791	-.847	-.616	-.320	-.009	.535	.890	.533	-.407	-.669
40.0	1.310	1.120	1.340	.956	.210	-.106	-.319	-.585	-.702	-.506	-.238	-.050	.280	.555	.331	-.250	-.436
37.5	1.565	1.295	1.175	.648	.049	-.044	-.230	-.489	-.616	-.418	-.195	-.028	.056	.216	.366	.156	-.213
35.0	1.750	1.470	1.080	.353	-.014	-.016	-.193	-.473	-.573	-.389	-.181	-.034	-.093	-.055	.504	.674	.100
34.0	1.800	1.530	1.070	.261	-.054	-.028	-.191	-.456	-.539	-.377	-.170	-.039	-.141	-.142	.515	.851	.242
33.0	1.830	1.560	1.060	.197	-.105	-.051	-.188	-.426	-.493	-.360	-.155	-.035	-.182	-.225	.489	.987	.372
32.0	1.840	1.560	1.030	.163	-.157	-.082	-.183	-.385	-.435	-.338	-.140	-.021	-.215	-.309	.431	1.080	.472
31.0	1.800	1.540	.988	.152	-.197	-.115	-.179	-.339	-.366	-.310	-.122	-.005	-.242	-.388	.359	1.120	.529
30.0	1.740	1.500	.939	.151	-.219	-.142	-.177	-.289	-.291	-.277	-.103	-.002	-.266	-.455	.288	1.120	.540
29.0	1.640	1.450	.892	.151	-.225	-.160	-.174	-.237	-.216	-.240	-.083	-.022	-.288	-.502	.230	1.090	.505
28.0	1.530	1.390	.849	.145	-.222	-.172	-.162	-.184	-.149	-.201	-.061	-.062	-.307	-.528	.185	1.030	.436
27.0	1.420	1.330	.806	.129	-.217	-.185	-.135	-.130	-.095	-.161	-.039	-.109	-.318	-.535	.147	.959	.344
26.0	1.320	1.270	.758	.106	-.219	-.201	-.097	-.077	-.057	-.122	-.020	-.149	-.321	-.528	.113	.889	.241
25.0	1.240	1.220	.703	.077	-.230	-.220	-.059	-.025	-.031	-.087	-.007	-.168	-.313	-.511	.080	.831	.140
24.0	1.180	1.160	.642	.043	-.245	-.236	-.036	.020	-.013	-.059	-.003	-.164	-.292	-.486	.057	.790	.048
23.0	1.140	1.110	.581	.008	-.255	-.243	-.036	.054	.001	-.041	-.012	-.141	-.261	-.456	.050	.759	-.028
22.0	1.100	1.060	.521	-.026	-.252	-.241	-.054	.073	.018	-.032	-.032	-.110	-.219	-.422	.059	.732	-.090
21.0	1.050	1.010	.461	-.058	-.234	-.233	-.080	.082	.041	-.027	-.061	-.086	-.173	-.383	.079	.699	-.140
20.0	.986	.957	.399	-.086	-.202	-.228	-.104	.090	.074	-.020	-.095	-.077	-.128	-.342	.103	.654	-.182
19.0	.898	.910	.337	-.104	-.152	-.228	-.134	.098	.127	-.015	-.140	-.086	-.086	-.297	.131	.594	-.212
18.0	.795	.883	.293	-.097	-.085	-.254	-.210	.098	.266	-.018	-.200	-.124	-.054	-.240	.172	.530	-.219
17.0	.669	.877	.267	-.078	-.043	-.363	-.390	.091	.692	-.013	-.360	-.240	-.060	-.194	.214	.461	-.212
16.0	.535	.827	.252	-.056	-.043	-.501	-.683	.244	1.190	-.008	-.540	-.320	-.016	-.125	.241	.390	-.163
15.0	.407	.708	.242	-.038	-.080	-.611	-1.040	.624	1.580	-.025	-.710	-.410	.118	-.018	.255	.320	-.082
14.0	.299	.550	.235	-.026	-.127	-.669	-1.400	1.150	1.800	-.089	-1.000	-.500	.307	.112	.279	.258	-.002
13.0	.215	.411	.233	-.011	-.166	-.694	-1.700	1.660	1.970	-.202	-1.200	-.600	.460	.237	.332	.211	.054
12.0	.154	.333	.241	.015	-.201	-.726	-1.940	2.020	2.200	-.339	-1.400	-.700	.503	.339	.412	.179	.074
10.0	.072	.265	.247	.091	-.296	-.796	-2.100	2.340	2.520	-.576	-1.870	-.902	.377	.511	.522	.125	.053
8.0	.002	.217	.269	.172	-.374	-.799	-1.850	2.240	2.280	-.690	-1.630	-.820	.202	.633	.541	.073	-.024
6.0	-.077	.193	.279	.189	-.382	-.755	-1.460	1.810	1.860	-.523	-1.310	-.667	-.003	.690	.525	.020	-.087
4.0	-.095	.167	.213	.131	-.279	-.653	-1.180	1.350	1.420	-.196	-1.030	-.521	-.108	.657	.400	.004	-.129
2.0	-.052	.105	.123	.048	-.141	-.414	-.779	.819	.844	.002	-.628	-.294	-.067	.376	.196	.012	-.120
0.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

T (IN UNITS OF 100. DEGREES KELVIN) FOR JULY

				SOUTH				LATITUDE (DEGREES)						NORTH			
ALT(KM)	80	70	60	50	40	30	20	10	0	10	20	30	40	50	60	70	80
50.0	2.523	2.540	2.567	2.599	2.635	2.665	2.689	2.710	2.717	2.709	2.694	2.706	2.724	2.752	2.792	2.830	2.870
47.5	2.501	2.515	2.536	2.572	2.614	2.646	2.658	2.688	2.695	2.692	2.680	2.690	2.704	2.734	2.769	2.802	2.827
45.0	2.449	2.462	2.483	2.517	2.563	2.603	2.625	2.643	2.648	2.647	2.639	2.648	2.662	2.690	2.724	2.756	2.770
42.5	2.389	2.404	2.424	2.455	2.498	2.538	2.563	2.578	2.583	2.582	2.578	2.583	2.598	2.624	2.658	2.691	2.702
40.0	2.323	2.341	2.367	2.400	2.440	2.477	2.502	2.515	2.520	2.518	2.517	2.521	2.535	2.558	2.591	2.620	2.630
37.5	2.255	2.276	2.308	2.347	2.388	2.423	2.446	2.459	2.464	2.465	2.464	2.468	2.480	2.501	2.529	2.555	2.564
35.0	2.189	2.213	2.250	2.295	2.338	2.373	2.396	2.409	2.413	2.414	2.413	2.417	2.429	2.448	2.473	2.493	2.504
34.0	2.163	2.188	2.227	2.274	2.319	2.354	2.377	2.389	2.393	2.393	2.394	2.397	2.410	2.427	2.452	2.472	2.481
33.0	2.136	2.164	2.204	2.253	2.299	2.335	2.360	2.370	2.373	2.374	2.374	2.378	2.390	2.407	2.431	2.452	2.461
32.0	2.109	2.140	2.183	2.233	2.280	2.317	2.343	2.351	2.354	2.354	2.355	2.359	2.371	2.387	2.411	2.433	2.442
31.0	2.082	2.115	2.162	2.214	2.262	2.300	2.325	2.334	2.335	2.335	2.338	2.341	2.353	2.366	2.391	2.414	2.424
30.0	2.055	2.093	2.142	2.194	2.243	2.283	2.308	2.315	2.317	2.316	2.320	2.324	2.335	2.346	2.371	2.395	2.408
29.0	2.029	2.071	2.123	2.175	2.225	2.265	2.290	2.295	2.297	2.297	2.300	2.306	2.315	2.327	2.352	2.378	2.392
28.0	2.005	2.051	2.105	2.155	2.206	2.248	2.273	2.277	2.278	2.278	2.282	2.289	2.297	2.308	2.334	2.362	2.377
27.0	1.981	2.031	2.088	2.139	2.190	2.233	2.256	2.258	2.259	2.259	2.265	2.271	2.280	2.292	2.318	2.347	2.363
26.0	1.960	2.014	2.074	2.125	2.176	2.218	2.239	2.239	2.239	2.240	2.246	2.253	2.261	2.277	2.304	2.334	2.351
25.0	1.940	1.998	2.061	2.114	2.166	2.204	2.220	2.219	2.219	2.219	2.226	2.235	2.244	2.263	2.291	2.322	2.340
24.0	1.924	1.985	2.051	2.107	2.157	2.189	2.201	2.198	2.197	2.196	2.205	2.216	2.229	2.250	2.280	2.313	2.332
23.0	1.913	1.976	2.044	2.103	2.151	2.175	2.182	2.176	2.173	2.173	2.182	2.197	2.214	2.240	2.271	2.305	2.326
22.0	1.907	1.971	2.042	2.103	2.147	2.163	2.161	2.151	2.147	2.147	2.159	2.177	2.200	2.230	2.264	2.300	2.321
21.0	1.906	1.971	2.044	2.106	2.145	2.152	2.138	2.124	2.119	2.120	2.133	2.157	2.186	2.224	2.261	2.296	2.318
20.0	1.908	1.974	2.052	2.114	2.145	2.137	2.113	2.092	2.086	2.089	2.104	2.133	2.172	2.217	2.260	2.295	2.317
19.0	1.915	1.980	2.062	2.124	2.147	2.123	2.082	2.053	2.044	2.049	2.069	2.104	2.155	2.211	2.260	2.297	2.319
18.0	1.926	1.989	2.072	2.136	2.152	2.109	2.043	2.008	1.995	2.004	2.029	2.073	2.137	2.207	2.264	2.302	2.321
17.0	1.938	1.999	2.080	2.144	2.153	2.097	2.019	1.973	1.959	1.971	1.997	2.047	2.124	2.207	2.272	2.309	2.326
16.0	1.951	2.009	2.086	2.149	2.156	2.097	2.019	1.979	1.969	1.979	1.997	2.044	2.119	2.210	2.278	2.314	2.330
15.0	1.962	2.017	2.092	2.155	2.166	2.114	2.056	2.031	2.027	2.032	2.039	2.071	2.130	2.213	2.281	2.316	2.332
14.0	1.971	2.023	2.095	2.158	2.174	2.141	2.115	2.107	2.108	2.109	2.110	2.122	2.154	2.214	2.275	2.311	2.329
13.0	1.977	2.027	2.095	2.156	2.180	2.173	2.180	2.186	2.189	2.190	2.189	2.187	2.190	2.218	2.263	2.297	2.322
12.0	1.981	2.032	2.096	2.153	2.189	2.211	2.243	2.259	2.266	2.267	2.264	2.253	2.238	2.235	2.253	2.277	2.303
10.0	2.017	2.074	2.135	2.199	2.261	2.319	2.372	2.393	2.409	2.410	2.403	2.390	2.364	2.326	2.290	2.270	2.269
8.0	2.125	2.178	2.239	2.307	2.380	2.450	2.507	2.533	2.546	2.546	2.538	2.525	2.496	2.451	2.401	2.361	2.338
6.0	2.237	2.287	2.353	2.427	2.506	2.580	2.633	2.662	2.673	2.673	2.663	2.650	2.617	2.570	2.528	2.488	2.453
4.0	2.347	2.394	2.462	2.545	2.632	2.703	2.751	2.778	2.790	2.789	2.780	2.767	2.733	2.685	2.643	2.600	2.561
2.0	2.445	2.495	2.570	2.657	2.739	2.806	2.854	2.879	2.890	2.889	2.881	2.868	2.836	2.789	2.744	2.703	2.668
0.0	2.530	2.590	2.670	2.753	2.825	2.889	2.943	2.966	2.977	2.976	2.971	2.960	2.928	2.883	2.838	2.793	2.744

KZZ (IN UNITS OF .00001 KMSQ/SEC)   FOR   JULY

	SOUTH							LATITUDE (DEGREES)						NORTH			
ALT(KM)	80	70	60	50	40	30	20	10	0	10	20	30	40	50	60	70	80
50.0	2.669	2.669	2.669	5.484	4.895	.965	.203	.184	.208	.188	.201	.233	.443	1.448	1.261	1.261	1.261
47.5	2.003	2.003	2.003	4.114	3.673	.724	.152	.138	.156	.141	.151	.175	.332	1.086	.946	.946	.946
45.0	1.503	1.503	1.503	3.087	2.755	.543	.114	.103	.117	.106	.113	.131	.249	.815	.710	.710	.710
42.5	1.127	1.127	1.127	2.316	2.067	.408	.086	.078	.088	.079	.085	.098	.187	.611	.532	.532	.532
40.0	.846	.846	.846	1.737	1.551	.306	.064	.058	.066	.060	.064	.074	.140	.459	.399	.399	.399
37.5	.634	.634	.634	1.303	1.164	.229	.048	.044	.049	.045	.048	.055	.105	.344	.300	.300	.300
35.0	.476	.476	.476	.978	.873	.172	.036	.033	.037	.034	.036	.042	.079	.253	.225	.225	.225
34.0	.424	.424	.424	.872	.778	.153	.032	.029	.033	.030	.032	.037	.070	.230	.200	.200	.200
33.0	.378	.378	.378	.777	.694	.137	.029	.026	.029	.027	.028	.033	.063	.205	.179	.179	.179
32.0	.337	.337	.337	.693	.618	.122	.026	.023	.026	.024	.025	.029	.056	.183	.159	.159	.159
31.0	.301	.301	.301	.617	.551	.109	.023	.021	.023	.021	.023	.026	.050	.163	.142	.142	.142
30.0	.268	.268	.268	.550	.491	.097	.020	.018	.021	.019	.020	.023	.044	.145	.127	.127	.127
29.0	.239	.239	.239	.491	.438	.086	.018	.016	.019	.017	.018	.021	.040	.130	.113	.113	.113
28.0	.213	.213	.213	.437	.390	.077	.016	.015	.017	.015	.016	.019	.035	.115	.101	.101	.101
27.0	.190	.190	.190	.390	.348	.069	.014	.013	.015	.013	.014	.017	.032	.103	.090	.090	.090
26.0	.169	.169	.169	.348	.310	.061	.013	.012	.013	.012	.013	.015	.028	.092	.080	.080	.080
25.0	.151	.151	.151	.310	.277	.055	.011	.010	.012	.011	.011	.013	.025	.082	.071	.071	.071
24.0	.134	.134	.134	.276	.247	.049	.010	.009	.010	.009	.010	.012	.022	.073	.063	.063	.063
23.0	.120	.120	.120	.246	.220	.043	.009	.008	.009	.008	.009	.010	.020	.065	.057	.057	.057
22.0	.107	.107	.107	.219	.196	.039	.008	.007	.008	.008	.008	.009	.018	.058	.050	.050	.050
21.0	.095	.095	.095	.196	.175	.034	.007	.007	.007	.007	.007	.008	.016	.052	.045	.045	.045
20.0	.085	.085	.085	.174	.156	.031	.006	.006	.007	.006	.006	.007	.014	.046	.040	.040	.040
19.0	.089	.089	.089	.166	.161	.076	.019	.008	.012	.012	.016	.019	.045	.056	.042	.042	.042
18.0	.093	.093	.093	.159	.167	.120	.032	.010	.018	.017	.026	.031	.076	.066	.044	.044	.044
17.0	.097	.097	.097	.151	.173	.165	.044	.012	.023	.023	.036	.043	.107	.076	.046	.046	.046
16.0	.101	.101	.101	.143	.174	.196	.056	.016	.029	.028	.045	.056	.138	.086	.048	.048	.048
15.0	.102	.102	.102	.139	.156	.171	.061	.026	.057	.027	.043	.055	.136	.113	.064	.064	.064
14.0	.103	.103	.103	.136	.139	.146	.066	.036	.086	.026	.041	.054	.134	.140	.080	.080	.080
13.0	.104	.104	.104	.132	.122	.121	.071	.046	.114	.025	.039	.053	.133	.167	.096	.096	.096
12.0	.107	.107	.107	.128	.105	.096	.090	.060	.140	.034	.052	.069	.131	.195	.140	.059	.055
10.0	.090	.090	.090	.125	.392	.151	.143	.102	.208	.064	.091	.115	.198	.177	.135	.072	.076
8.0	.097	.097	.095	.282	.709	.239	.229	.175	.311	.120	.160	.192	.297	.221	.155	.070	.102
6.0	.176	.186	.193	.424	.854	.379	.366	.300	.463	.226	.281	.321	.444	.357	.284	.110	.140
4.0	.363	.373	.381	.641	1.030	.599	.535	.512	.687	.425	.491	.536	.666	.576	.496	.263	.303
2.0	.735	.748	.756	.977	1.243	.948	.937	.877	1.017	.798	.858	.897	.999	.929	.865	.627	.665
0.0	1.500	1.500	1.500	1.500	1.500	1.500	1.500	1.500	1.500	1.500	1.500	1.500	1.500	1.500	1.500	1.500	1.500

KFZ (IN UNITS OF .001 KMSQ/SEC)   FOR   JULY

ALT(KM)	SOUTH 80	70	60	50	40	30	20	LATITUDE (DEGREES) 10	0	10	20	30	40	NORTH 50	60	70	80
50.0	.540	1.227	1.635	1.642	2.237	.547	-.011	-.004	-.022	-.030	-.024	-.038	-.030	-.177	-.177	-.133	-.059
47.5	.635	1.444	1.925	1.932	2.237	.547	-.012	-.003	-.022	-.029	-.023	-.038	-.030	-.177	-.177	-.133	-.059
45.0	.731	1.660	2.214	2.222	2.495	.581	-.012	-.002	-.022	-.029	-.022	-.039	-.030	-.188	-.188	-.141	-.062
42.5	.750	1.705	2.274	2.283	2.472	.511	-.009	-.002	-.021	-.028	-.021	-.039	-.026	-.186	-.186	-.140	-.062
40.0	.770	1.750	2.334	2.343	2.450	.440	-.007	-.002	-.019	-.026	-.020	-.038	-.021	-.185	-.185	-.139	-.061
37.5	.758	1.722	2.297	2.306	2.519	.346	-.005	-.002	-.017	-.027	-.020	-.042	-.009	-.179	-.179	-.134	-.059
35.0	.746	1.695	2.259	2.269	2.588	.253	-.004	-.002	-.014	-.027	-.020	-.046	.003	-.173	-.173	-.130	-.057
34.0	.755	1.715	2.287	2.297	2.488	.244	-.003	-.001	-.014	-.027	-.020	-.045	-.004	-.175	-.175	-.131	-.058
33.0	.764	1.736	2.315	2.325	2.390	.236	-.003	-.001	-.014	-.028	-.020	-.044	-.010	-.176	-.176	-.132	-.058
32.0	.773	1.757	2.343	2.352	2.291	.227	-.002	-.001	-.014	-.028	-.020	-.043	-.016	-.178	-.178	-.134	-.059
31.0	.782	1.778	2.371	2.380	2.192	.219	-.002	-.001	-.014	-.029	-.020	-.042	-.023	-.180	-.180	-.135	-.059
30.0	.791	1.799	2.399	2.408	2.093	.211	-.001	-.001	-.014	-.029	-.020	-.041	-.029	-.161	-.181	-.136	-.060
29.0	.773	1.758	2.343	2.353	2.010	.224	-.002	-.001	-.016	-.030	-.022	-.044	-.042	-.197	-.197	-.148	-.065
28.0	.755	1.716	2.288	2.298	1.927	.237	-.002	-.002	-.017	-.031	-.023	-.047	-.054	-.213	-.213	-.160	-.070
27.0	.737	1.675	2.233	2.242	1.844	.250	-.003	-.002	-.019	-.032	-.025	-.049	-.066	-.229	-.229	-.172	-.076
26.0	.719	1.634	2.178	2.187	1.761	.263	-.004	-.003	-.020	-.033	-.027	-.052	-.078	-.245	-.245	-.184	-.081
25.0	.701	1.593	2.123	2.132	1.678	.277	-.004	-.003	-.022	-.034	-.028	-.055	-.090	-.261	-.261	-.196	-.086
24.0	.702	1.595	2.126	2.134	1.596	.290	-.005	-.004	-.023	-.035	-.030	-.057	-.103	-.275	-.275	-.206	-.091
23.0	.703	1.597	2.129	2.137	1.513	.303	-.006	-.004	-.025	-.036	-.031	-.060	-.115	-.289	-.289	[illegible]	-.095
22.0	.703	1.599	2.132	2.139	1.430	.316	-.006	-.004	-.026	[illegible]	-.033	-.062	-.127	-.303	-.303	-.227	-.100
21.0	.704	1.601	2.134	2.141	1.347	.330	-.007	-.005	-.028	-.037	-.035	-.065	-.139	-.317	-.317	-.238	-.105
20.0	.705	1.603	2.137	2.144	1.264	.343	-.008	-.005	-.029	[illegible]	-.036	-.068	-.152	-.331	-.331	-.248	-.109
19.0	.701	1.592	2.123	2.131	1.399	.801	.173	.026	-.079	-.095	-.127	-.194	-.387	-.432	-.432	-.324	-.143
18.0	.696	1.582	2.109	2.118	1.533	1.260	.355	.057	-.129	-.151	-.217	-.321	[illegible]	-.533	-.533	-.400	-.176
17.0	.691	1.571	2.095	2.105	1.667	1.718	.536	.088	-.179	-.207	-.308	-.448	-.858	-.634	-.634	-.476	-.209
16.0	.685	1.556	2.075	2.086	1.759	1.935	.630	.090	-.242	-.244	-.372	-.531	-1.046	-.781	-.781	-.586	-.258
15.0	.796	1.809	2.412	2.424	1.680	1.131	.379	-.023	-.352	-.201	-.330	-.420	-1.045	-1.094	-1.094	-.820	-.361
14.0	.905	2.056	2.742	2.757	1.602	.390	.128	-.094	-.459	-.159	-.289	-.316	-1.045	-1.412	-1.412	-1.059	-.466
13.0	1.013	2.303	3.071	3.088	1.523	-.100	-.093	-.100	-.567	-.112	-.248	-.234	-1.044	-1.736	-1.736	-1.302	-.573
12.0	1.122	2.549	3.399	3.420	1.445	-.100	-.100	-.100	-.672	-.063	-.204	-.212	-1.043	-2.062	-2.062	-1.546	-.680
10.0	-.100	-.100	-.032	-.100	-.100	-.100	-.100	-.100	-.185	.094	.100	.100	.100	.099	-.187	-.186	.054
8.0	-.100	-.095	-.100	-.100	-.100	-.100	-.100	-.100	-.014	.024	.100	.100	.100	.100	.100	-.042	.100
6.0	-.100	-.094	.140	-.100	-.100	-.100	-.098	-.100	-.139	-.188	.081	.100	.100	.100	-.164	-.517	-.150
4.0	.130	.161	1.819	1.494	-.100	-.100	-.100	.008	.016	-.012	.098	.100	.067	-.191	-.674	-.920	-.480
2.0	.390	.756	2.660	3.238	1.554	.387	-.070	-.040	.011	.029	.098	.028	-.419	-.641	-.983	-1.176	-.682
0.0	.296	.565	1.962	2.869	1.710	1.042	.215	-.072	-.035	-.130	.070	-.230	-.382	-.486	-.767	-.921	-.552

KFF (IN UNITS OF KMSQ/SEC) FOR JULY

	SOUTH							LATITUDE (DEGREES)						NORTH			
ALT(KM)	80	70	60	50	40	30	20	10	0	10	20	30	40	50	60	70	80
50.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
47.5	7.324	7.574	7.292	6.157	5.070	2.541	1.778	1.038	.529	.418	.383	.560	.353	.314	.329	.442	.434
45.0	6.683	7.420	7.021	5.831	4.630	2.194	1.475	.861	.426	.323	.281	.468	.308	.258	.242	.364	.395
42.5	6.013	6.454	6.255	5.232	4.019	1.723	1.064	.689	.348	.273	.249	.386	.259	.215	.198	.362	.375
40.0	5.343	5.488	5.488	4.631	3.408	1.251	.653	.517	.270	.224	.218	.304	.209	.172	.155	.361	.354
37.5	4.549	4.582	4.667	4.127	3.142	.910	.474	.363	.212	.202	.198	.271	.171	.143	.143	.312	.310
35.0	3.755	3.675	3.846	3.623	2.876	.569	.296	.210	.154	.181	.178	.240	.133	.114	.132	.263	.266
34.0	3.452	3.388	3.650	3.541	2.689	.532	.263	.195	.147	.177	.175	.227	.134	.110	.132	.257	.258
33.0	3.148	3.100	3.454	3.459	2.501	.496	.230	.180	.141	.174	.172	.214	.135	.107	.132	.251	.250
32.0	2.844	2.812	3.257	3.377	2.313	.459	.197	.165	.134	.170	.168	.201	.136	.103	.131	.244	.242
31.0	2.541	2.524	3.060	3.295	2.125	.423	.165	.150	.128	.167	.165	.188	.138	.100	.130	.237	.234
30.0	2.237	2.237	2.864	3.213	1.937	.386	.132	.135	.122	.163	.161	.175	.139	.096	.129	.230	.225
29.0	2.367	2.405	2.886	3.074	1.831	.396	.148	.154	.131	.163	.166	.179	.147	.110	.133	.208	.206
28.0	2.496	2.573	2.909	2.935	1.725	.405	.163	.173	.141	.164	.171	.183	.155	.124	.136	.186	.186
27.0	2.626	2.741	2.932	2.796	1.619	.414	.179	.191	.150	.164	.175	.187	.163	.138	.139	.164	.166
26.0	2.756	2.909	2.954	2.658	1.513	.423	.194	.210	.160	.165	.180	.191	.171	.152	.143	.141	.146
25.0	2.885	3.076	2.977	2.519	1.406	.432	.210	.228	.169	.165	.184	.195	.179	.166	.147	.119	.127
24.0	3.014	3.244	3.000	2.380	1.300	.441	.226	.247	.178	.165	.189	.199	.188	.180	.150	.097	.106
23.0	3.144	3.413	3.023	2.241	1.194	.451	.241	.266	.188	.166	.193	.203	.196	.194	.153	.074	.087
22.0	3.273	3.581	3.046	2.102	1.088	.460	.256	.284	.197	.167	.198	.207	.204	.208	.156	.052	.067
21.0	3.403	3.749	3.069	1.963	.982	.469	.272	.303	.206	.167	.203	.211	.212	.222	.160	.030	.047
20.0	3.532	3.917	3.092	1.824	.875	.478	.288	.321	.216	.167	.207	.215	.220	.236	.163	.007	.027
19.0	3.344	3.715	3.003	1.868	1.056	.767	.505	.457	.244	.210	.269	.325	.344	.321	.208	.055	.046
18.0	3.156	3.514	2.913	1.912	1.237	1.056	.723	.592	.271	.253	.332	.436	.467	.405	.253	.104	.066
17.0	2.967	3.312	2.824	1.955	1.417	1.345	.940	.727	.298	.296	.394	.546	.591	.489	.299	.153	.085
16.0	2.810	3.153	2.798	2.094	1.705	1.740	1.206	.866	.329	.338	.460	.669	.770	.638	.391	.229	.129
15.0	2.776	3.161	3.019	2.614	2.422	2.561	1.664	1.015	.372	.376	.536	.844	1.170	1.048	.671	.417	.275
14.0	2.743	3.170	3.240	3.136	3.138	3.383	2.122	1.165	.416	.414	.613	1.018	1.569	1.457	.951	.605	.421
13.0	2.709	3.178	3.461	3.656	3.855	4.204	2.581	1.315	.459	.452	.689	1.193	1.969	1.867	1.231	.793	.568
12.0	2.675	3.187	3.682	4.177	4.572	5.025	3.039	1.465	.502	.490	.765	1.367	2.358	2.277	1.512	.982	.714
10.0	3.492	4.151	5.060	5.900	5.794	4.695	2.555	1.210	.365	.324	.505	1.040	2.122	2.708	2.396	1.930	1.634
8.0	3.772	4.393	5.189	5.899	5.296	3.515	1.793	.848	.237	.196	.302	.675	1.494	2.252	2.263	1.989	1.714
6.0	2.965	3.410	3.862	4.187	3.494	2.211	1.075	.512	.171	.164	.230	.460	.903	1.373	1.416	1.298	1.115
4.0	1.942	2.216	2.543	2.701	2.183	1.463	.662	.330	.130	.156	.227	.393	.609	.899	.903	.803	.702
2.0	1.241	1.378	1.632	1.724	1.424	.989	.428	.242	.130	.154	.233	.339	.453	.612	.577	.511	.495
0.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

V (IN UNITS OF .001 KM/SEC) FOR JULY

ALT(KM)	SOUTH 80	70	60	50	40	30	20	LATITUDE (DEGREES) 10	0	10	20	30	40	NORTH 50	60	70	80
50.0	.091	.134	.144	.133	.065	-.032	-.057	-.016	.021	.028	.034	-.057	-.143	-.136	-.132	-.128	-.104
47.5	-.025	-.059	-.089	-.075	-.259	-.496	-.688	-.763	-.748	-.636	-.492	-.314	-.196	-.185	-.187	-.088	.265
45.0	-.072	-.158	-.188	-.208	-.410	-.646	-.820	-.926	-.966	-.948	-.864	-.709	-.548	-.424	-.295	-.120	.221
42.5	-.064	-.097	-.060	-.109	-.385	-.661	-.870	-1.015	-1.117	-1.165	-1.104	-.954	-.736	-.494	-.277	-.066	.253
40.0	-.064	-.039	.074	.011	-.246	-.444	-.609	-.737	-.846	-.926	-.916	-.840	-.681	-.450	-.230	-.040	.200
37.5	-.090	-.039	.107	.030	-.149	-.220	-.271	-.343	-.430	-.492	-.507	-.507	-.441	-.309	-.157	-.024	.111
35.0	-.115	-.057	.086	-.007	-.099	-.081	-.058	-.091	-.127	-.134	-.145	-.166	-.178	-.186	-.126	-.067	-.056
34.0	-.087	-.033	.089	.007	-.067	-.043	-.004	-.020	-.034	-.016	-.018	-.046	-.085	-.140	-.127	-.096	-.117
33.0	-.050	.005	.101	.045	-.022	-.007	.031	.030	.042	.079	.086	.060	.006	-.075	-.094	-.088	-.136
32.0	-.032	.033	.101	.080	.029	.031	.058	.067	.101	.150	.165	.152	.089	.006	-.025	-.035	-.079
31.0	-.024	.046	.095	.104	.067	.054	.065	.084	.139	.188	.212	.206	.141	.066	.024	-.005	-.059
30.0	-.029	.042	.090	.117	.088	.064	.058	.085	.156	.204	.226	.229	.167	.107	.062	.021	-.045
29.0	-.029	.035	.087	.127	.098	.067	.051	.078	.157	.199	.218	.225	.177	.129	.083	.039	-.026
28.0	-.031	.022	.079	.123	.091	.056	.036	.061	.137	.175	.189	.196	.169	.136	.085	.039	-.020
27.0	-.037	.008	.068	.109	.074	.037	.018	.041	.107	.140	.151	.157	.154	.137	.082	.043	.014
26.0	-.041	.002	.058	.085	.054	.014	-.007	.012	.062	.094	.103	.111	.129	.121	.065	.036	.035
25.0	-.048	.002	.050	.059	.040	-.006	-.037	-.027	.006	.038	.047	.061	.095	.093	.041	.024	.047
24.0	-.052	.012	.049	.043	.034	-.019	-.071	-.072	-.055	-.026	-.018	.003	.047	.050	.010	.007	.041
23.0	-.054	.028	.062	.045	.040	-.022	-.099	-.117	-.111	-.092	-.088	-.066	-.019	-.008	-.025	-.011	.027
22.0	-.056	.048	.088	.069	.055	-.018	-.114	-.148	-.154	-.148	-.153	-.139	-.094	-.071	-.061	-.026	.017
21.0	-.061	.068	.127	.109	.075	-.011	-.116	-.164	-.178	-.183	-.197	-.199	-.164	-.130	-.094	-.046	-.009
20.0	-.073	.085	.170	.162	.102	-.006	-.114	-.169	-.183	-.188	-.208	-.230	-.204	-.163	-.113	-.060	-.035
19.0	-.095	.102	.203	.181	.098	-.005	-.107	-.165	-.167	-.149	-.176	-.226	-.209	-.158	-.102	-.051	-.032
18.0	-.147	.102	.275	.256	.154	.070	-.097	-.220	-.176	-.042	-.058	-.185	-.205	-.145	-.077	-.024	-.013
17.0	-.153	.071	.282	.296	.225	.179	-.117	-.451	-.332	-.017	.039	-.092	-.161	-.131	-.067	-.018	-.015
16.0	-.062	.023	.135	.155	.175	.207	-.264	-.900	-.696	-.213	-.012	.015	-.070	-.113	-.084	-.058	-.070
15.0	.056	-.016	-.063	-.067	.036	.143	-.511	-1.472	-1.190	-.563	-.174	.072	.007	-.103	-.115	-.120	-.155
14.0	.119	-.026	-.173	-.207	-.083	.034	-.755	-1.943	-1.602	-.855	-.300	.087	.058	-.058	-.073	-.066	-.036
13.0	.090	-.012	-.131	-.172	-.095	-.054	-.870	-2.104	-1.741	-.939	-.315	.054	.040	-.030	-.015	.023	.118
12.0	.022	.000	-.019	-.017	.007	-.097	-.808	-1.899	-1.581	-.830	-.252	.014	-.007	-.040	-.001	.053	.148
10.0	-.054	-.011	.066	.139	.127	-.136	-.514	-1.134	-.955	-.481	-.136	.002	-.029	-.050	-.003	.053	.108
8.0	-.058	-.024	.038	.089	.086	-.117	-.267	-.532	-.400	-.179	-.060	-.001	-.032	-.060	-.026	.005	-.011
6.0	-.021	-.016	.006	.010	.024	-.058	-.063	-.076	.026	.060	.028	.009	-.010	-.030	-.016	-.005	-.039
4.0	.020	-.004	-.017	-.040	-.031	.010	.183	.503	.449	.246	.090	.012	.019	.017	.005	-.009	-.037
2.0	.034	.008	-.040	-.066	-.079	.082	.481	1.099	.859	.404	.132	.011	.046	.080	.041	-.002	-.017
0.0	.008	.003	-.056	-.087	-.066	.082	.369	.573	.236	-.206	-.247	-.036	.134	.206	.103	.004	-.052

W (IN UNITS OF .000001 KM/SEC)   FOR   JULY

ALT(KM)	SOUTH 80	70	60	50	40	30	20	LATITUDE (DEGREES) 10	0	10	20	30	40	NORTH 50	60	70	80
50.0	-9.860	-9.480	-7.840	-6.100	-4.910	-3.390	-1.870	-.640	.426	1.380	2.690	3.170	3.230	3.160	2.930	3.580	5.550
47.5	-6.935	-6.615	-5.595	-4.505	-4.190	-3.075	-1.780	-.507	.456	1.410	2.405	2.685	2.460	2.165	2.055	2.880	4.680
45.0	-5.130	-4.980	-4.160	-3.390	-3.500	-2.700	-1.600	-.459	.413	1.200	1.930	2.220	1.940	1.690	1.770	2.590	4.200
42.5	-3.810	-3.695	-3.100	-2.770	-3.190	-2.530	-1.535	-.572	.204	.923	1.675	2.040	1.890	1.675	1.745	2.375	3.620
40.0	-2.710	-2.490	-2.070	-2.260	-2.990	-2.400	-1.550	-.697	-.042	.649	1.440	1.880	1.950	1.840	1.770	2.160	2.980
37.5	-1.960	-1.540	-1.210	-1.820	-2.530	-1.950	-1.360	-.686	-.212	.363	1.090	1.510	1.785	1.805	1.680	1.850	2.360
35.0	-1.480	-.882	-.638	-1.500	-1.960	-1.360	-1.000	-.598	-.265	.200	.763	1.060	1.410	1.500	1.480	1.480	1.820
34.0	-1.320	-.684	-.475	-1.380	-1.730	-1.130	-.856	-.549	-.240	.180	.642	.892	1.210	1.300	1.360	1.350	1.630
33.0	-1.160	-.511	-.338	-1.250	-1.510	-.929	-.712	-.489	-.193	.177	.535	.734	1.000	1.080	1.230	1.210	1.460
32.0	-.994	-.358	-.226	-1.100	-1.310	-.766	-.583	-.417	-.133	.181	.448	.592	.791	.874	1.080	1.060	1.280
31.0	-.836	-.223	-.134	-.932	-1.130	-.640	-.476	-.338	-.067	.185	.381	.470	.596	.689	.912	.902	1.090
30.0	-.694	-.108	-.056	-.764	-.976	-.544	-.393	-.253	-.000	.182	.328	.369	.424	.533	.747	.740	.899
29.0	-.576	-.013	.016	-.604	-.844	-.472	-.330	-.171	.064	.172	.284	.289	.284	.404	.587	.587	.705
28.0	-.486	.060	.083	-.463	-.736	-.416	-.281	-.099	.120	.158	.245	.226	.181	.296	.438	.452	.523
27.0	-.420	.110	.141	-.349	-.651	-.369	-.240	-.041	.161	.142	.211	.179	.118	.208	.304	.342	.361
26.0	-.373	.143	.182	-.265	-.580	-.334	-.205	.001	.185	.130	.180	.149	.088	.134	.188	.262	.231
25.0	-.340	.166	.204	-.208	-.516	-.314	-.180	.027	.192	.126	.153	.135	.082	.074	.096	.211	.135
24.0	-.313	.189	.206	-.172	-.453	-.312	-.171	.040	.186	.129	.132	.137	.090	.028	.033	.184	.073
23.0	-.286	.219	.198	-.149	-.394	-.327	-.185	.041	.170	.131	.117	.150	.106	.004	.004	.179	.039
22.0	-.254	.264	.192	-.130	-.345	-.353	-.219	.031	.146	.125	.105	.165	.133	.007	.013	.191	.026
21.0	-.219	.328	.203	-.110	-.315	-.394	-.261	.009	.118	.107	.091	.172	.167	.039	.055	.218	.029
20.0	-.183	.413	.237	-.092	-.306	-.414	-.300	-.020	.090	.085	.072	.166	.203	.092	.116	.251	.041
19.0	-.156	.520	.296	-.063	-.323	-.454	-.329	-.047	.073	.069	.046	.147	.238	.147	.177	.280	.053
18.0	-.142	.643	.336	-.075	-.340	-.456	-.355	-.066	.084	.074	-.003	.104	.277	.202	.222	.290	.049
17.0	-.184	.822	.483	-.045	-.346	-.467	-.495	-.139	.218	.198	-.107	-.033	.296	.268	.266	.288	.008
16.0	-.210	.883	.583	.009	-.286	-.484	-.823	-.351	.516	.428	-.128	-.118	.230	.289	.295	.282	.006
15.0	-.179	.754	.539	.056	-.164	-.521	-1.380	-.752	.986	.752	.034	-.061	.074	.249	.304	.280	.077
14.0	-.096	.493	.358	.067	-.027	-.597	-2.130	-1.300	1.580	1.150	.381	.122	-.111	.173	.296	.281	.193
13.0	-.011	.251	.162	.052	.056	-.729	-2.920	-1.880	2.220	1.600	.804	.313	-.246	.115	.285	.278	.286
12.0	.028	.146	.071	.032	.058	-.913	-3.570	-2.380	2.790	2.020	1.160	.397	-.299	.108	.286	.268	.307
10.0	-.021	.206	.218	.139	-.094	-1.410	-4.040	-2.950	3.380	2.560	1.510	.370	-.323	.140	.319	.248	.232
8.0	-.121	.260	.327	.218	-.230	-1.670	-3.660	-2.890	3.300	2.520	1.490	.369	-.352	.139	.356	.225	.157
6.0	-.181	.251	.339	.215	-.252	-1.620	-3.080	-2.510	3.050	2.140	1.230	.308	-.354	.125	.368	.186	.084
4.0	-.145	.180	.262	.142	-.174	-1.340	-2.330	-1.890	2.530	1.590	.881	.203	-.239	.076	.318	.137	.054
2.0	-.070	.082	.157	.063	-.090	-.780	-1.280	-.938	1.380	.874	.445	.100	-.168	.021	.205	.079	.053
0.0	0.000	0.000	0.000	0.000	0.300	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000